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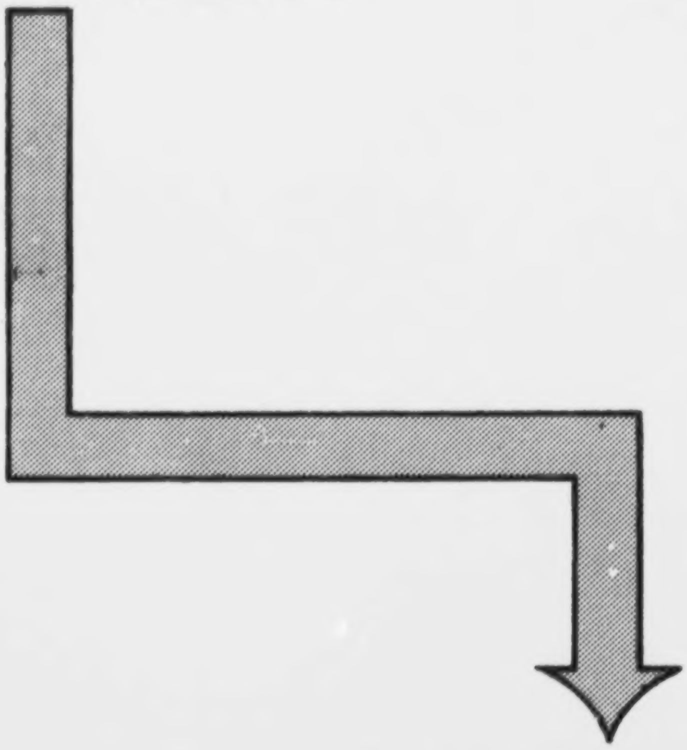

STUDIES RELATING TO MARKET PROJECTIONS FOR ADVANCED WASTE TREATMENT

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STUDIES RELATING TO MARKET PROJECTIONS FOR ADVANCED WASTE TREATMENT

by

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for

The Advanced Waste-Treatment Research Activities
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Cincinnati Water Research Laboratory
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Waste-Treatment Processes (AWTR). A variety of methods have been used to remove part of the pollutants from wastewater before it is discharged. In many situations, existing methods are not adequate to provide the degree of treatment required to control pollution effectively. Research in waste treatment is being directed at developing methods ranging from lower-cost or higher-efficiency versions of conventional treatment technology to total wastewater purification systems capable of removing virtually all pollutants and even of producing reusable effluents. The Federal Water Pollution Control Administration's research in this area covers the entire field of waste treatment including treatment of industrial wastes, with special emphasis given to waste-treatment methods capable of total pollution control and purification of wastewater for deliberate reuse. This subseries, Waste-Treatment Processes, contains reports on results of this research by the Administration.

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ABSTRACT

Full conventional waste water treatment will usually be applied before advanced treatment methods are required. To assess the present status of waste water treatment, the type of treatment now in use and the amount of waste water discharged were determined for the major streams in the country. About 4 percent of 100-mile river basins now have full secondary treatment. A study was made to determine the percentage of municipal waste water present in surface supplies of 155 cities of populations of 25,000 or more. The maximum was 18 percent, and the median was 3.5 percent.

Consideration was given in this study to the possibility of logistical imbalances that might occur if advanced waste treatment were applied to nearly all waste waters. If a distillation-adsorption system were used, less than 6 percent of the Nation's annual fuel consumption would be used and less than 0.5 percent of the total power generation would be required. Activated-carbon needs, however, would double. If electrodialysis were applied, 4 percent of the national power would be required. Membrane production would have to increase several thousandfold. Ultimate disposal of concentrates by injection, incineration, pipelining, etc., would create no imbalances.

STUDIES RELATING TO MARKET PROJECTIONS FOR ADVANCED WASTE TREATMENT

Chapter 1. Introduction

Through the Advanced Waste-Treatment Research Activities, the Federal Water Pollution Control Administration is engaged in the study of processes for treating various waste waters to make them indefinitely reusable. The impetus toward such studies arises from two distinct but related approaches. One of these, the "clean streams" impetus looks toward improving the quality of water in the nation's streams so that they may be beneficially used for a number of purposes. The other, the "more water" impetus, looks toward increasing the quantity of water available for municipal and industrial uses.

Advanced waste treatment (AWT) involves some radical departures from the existing methods of handling municipal and industrial water-borne wastes. While there is qualitative agreement on the desirability of such processes for application in particular instances where needed, there have been no quantitative data applicable to what, in commercial practice, would be called the economic and market research aspects. Such studies, in industrial practice, would include a determination of the costs of the processes or equipment, the total size of the market, the time schedule under which the market will develop, the geographical distribution of the market, the impact of competitive processes, and the capabilities or sizes of equipment in which the process will be used. In commercial practice, this information is of importance not only to the sales department, but also to the research and development department, since many aspects of the direction of the research and development are derived directly from such factors.

The present AWTR Activities were initiated and are sponsored and guided by a government agency; nevertheless the same planning and economic principles that would be employed in industry are also applicable to the government program.

Chapter 2. SUMMARY

In this investigation certain aspects of the economics of advanced waste treatment in the United States were explored. Streams receiving a major portion of municipal waste discharges that have had the highest possible degree of conventional treatment were identified. A survey was made to determine the extent to which the surface water supplies of 155 cities had previously been subjected to upstream waste discharges, treated or untreated. Advanced waste treatment itself and certain ultimate disposal methods were explored for possible logistical imbalances with regard to materials and resources.

STREAMS WITH COMPLETE TREATMENT

For each stream and stream reach in the nation greater than approximately 100 miles in length, the total upstream municipal waste discharge was cumulated. The cumulative fraction of biochemical oxygen demand (BOD) removed was weighted by the volume of discharge. This cumulative fraction serves as an index of the degree of treatment of the upstream waste water discharges. Streams having cumulative fractions of 0.9 or over are those for which all municipal discharges are already receiving the highest possible degree of conventional treatment. The lower the index, the less the probability that AWT would be called upon as the next step in stream improvement.

More than 4 percent of the 100-mile basins in the nation are now in the 0.9-and-over class; these basins constitute about 2 percent of the national land area. The volume of municipal effluent involved comprises 15 percent of the total recoverable municipal discharge reaching the nation's streams, excluding the small coastal basins. The actual volume involved is about 1.5 billion gallons per day(bgd) or over 1.5 million acre-feet per year, of which about 1.3 bgd is contrubuted by the city of Chicago. The geographic distribution of the "0.9 index" basins is highly concentrated in the Western Gulf and Mississippi River Basins, in which the percentages of waste flows amenable to AWT comprise about 23 and 28 percent, respectively, of the total recoverable municipal discharges. The only such basin east of the Mississippi is the DesPlaines River, to which Chicago contributes.

Basins with index numbers of 0.85 and over comprise 11 percent of the 100-mile basins and about 10 percent of the nation's area. Streams in this class receive about 2.2 bgd, or about 22 percent of the nation's recoverable municipal discharges. The two largest basin systems included, the Western Gulf and the Mississippi River Basins, receive 48 and 35 percent, respectively, of the waters with a 0.85-and-over index. Seven distinct basins east of the Mississippi are included in the 0.85-and-over index.

In any given basin having a large recoverable municipal discharge, the major portion of the total comes from relatively few cities.

Under the philosophy of the present study, the conclusion reached is that attaining a higher degree of pollution control for the great majority of the nation's streams at the present time, requires additional conventional treatment rather than advanced waste treatment. In a small, but not insignificant percentage of the nation's streams, the municipal waste discharges already receive maximum conventional treatment. For these streams, the next step in achieving a higher degree of pollution source control would be advanced waste treatment. The reader is cautioned that this study covers only one of the factors that enter into the determination of the market for AWT and that other factors may be of more importance in determining the market than the one under study.

WASTE IN SURFACE SUPPLIES

A study was made of the percentages of upstream municipal waste water present in the surface water supplies of 155 U.S. cities with a population of 25,000 or more. The study was an attempt to clarify the extent, nationwide, to which surface water supplies are composed of previously used water.

The sample data, representing 38 percent of all cities having surface water supplies and 34 percent of the U. S. population served by surface supplies, show that the range of upstream municipal waste water present in the source stream during low flow is from 0 to over 18 percent, with a median based on population served of 3.5 percent. The low flow is taken from the minimum flow month in the 1961 water year. In simpler terms, this analysis indicated that for the population experiencing median reuse, each 30 gallons of water flowing past their intake during the low flow month contained 1 gallon of water that had passed through the sewerage system of an upstream community. For the population experiencing the upper 10 percent of water reuse, the corresponding figure of 8 percent signifies that 1 gallon in 12 had passed through an upstream sewerage system.

The present study did not include upstream industrial discharges. If the national average ratio of industrial to municipal water withdrawals (approximately 14:1) were considered as applying to the municipal industrial waste volumes at each municipal intake, the median reuse factor (upstream waste discharges / low flow) would be of the order of 0.5 and for the worst cases in the sample, of the order of 3. Such reuse factors may be compared with the occasionally cited but poorly supported statements that the reuse factor (based on withdrawals rather than returns) for the Ohio river is 6, and for the Verdigris River in Kansas is 17, based on low flow. They also may be compared with a recent documented study giving the withdrawal reuse factor of 2.71 for the Ohio River at Cincinnati during low flow. The present study shows that such figures applicable to individual sites may not be at all unreasonable. A great deal depends upon the definition used for low flow, since the value varies greatly with various definitions.

If the current reuse factors developed in this study were considered appreciable by the public, such information could become a psychological advantage for advanced waste treatment rather than a psychological obstacle. If the reuse factor is considered excessive, there are but two choices: either drinking used water that has been deliberately processed by advanced techniques to remove all contaminants, or drinking used water that conventional processes may have treated inadequately.

LOGISTICAL IMBALANCES

In looking for possible logistical imbalances in AWT technology, the daily volume of municipal waste discharges was determined for about 11,000 communities. About 50 percent of the nation's waste water is produced in systems of less than 38 mgd, 30 percent in systems of greater than 100 mgd, and 30 percent in systems of less than about 4 mgd. The average sewage flow per community is about 1.25 mgd. An economic model of AWT plants, assuming that AWT was applied to every sewered community, was constructed from this distribution. When the model was used, however, it was found that the total consumptions of national resources were so small that the variations in unit consumption by size of plant were insignificant and need not have been taken into account.

Application of AWT in the form of distillation-adsorption systems would require a fuel consumption of less than 6 percent of the nation's total fuel production and an electrical energy consumption of less than 0.5 percent of the total power generation. The sulfuric acid used would be about 3.5 percent of U.S. production; however, the activated carbon used would be in the neighborhood of 360 tons per day, which is about twice the present production.

For AWT by adsorption-electrodialysis systems, which is another likely possibility, the fuel use would be negligible, the electrical energy about 4 percent of total national power generation, and the sulfuric acid consumption less than 3 percent of U.S. production. The activated carbon required, however, would amount to 560 tons per day, or over three times the present production. The production of electrodialysis membranes of course would be increased several thousandfold.

Exploration was also made for logistical imbalances in various methods of ultimate disposal of AWT wastes. For ultimate disposal by incineration, the impact on the economy in fuel, electrical energy, or railroad or tank truck hauling would be quite inconsequential.

For ultimate disposal by pipelining to the ocean, the amount of energy required would be insignificant compared to the national generation and the ton-miles of pipelining would be equivalent to about 6 percent of the current ton-miles for oil and oil products pipelining. These figures are insensitive to assumptions concerning the number of trunk pipelines. A figure for pipeline mileage is directly dependent upon the number of lines assumed and the distances. Assuming 100 trunk lines with an average haul of 700 miles, the AWT pipeline mileage would amount to about 17 percent of the present cross-country pipeline installations. Very preliminary studies from another project suggest, however, that optimum disposal by any method will comprise a pooling of the waste to be disposed, that the pattern of such group disposal by conveyance to the ocean will comprise a band around the coastline on the order of 100 miles wide, and that the conveyance in this band as well as the collection systems for other types of group disposal inland will be by truck or rail and not by pipeline. If that is the case, there will be no role for pipelining in ultimate disposal.

If every sewered community had one injection well (a highly unlikely situation in view of the group economy alluded to above), the number of such wells would be only 2 percent of the existing oil and gas wells. These could be completed within a single year with the existing well-drilling capacity of the nation. Waste injection wells will probably be deeper than the average oil and gas well. If the average depth were 10,000 feet, the total footage would represent about one-half of the annual footage in the oil and gas industry. Since, however, probably not more than one-half of the nation is suitable for injection-well disposal, the above figures must be reduced correspondingly.

PER CAPITA WASTE FLOWS

Some studies made in connection with the processing of the basic data provide information not heretofore available. The average per capita municipal waste flow was determined for population categories of less than 10,000, 10,000 to 100,000, and greater than 100,000 for each state. The national averages were 131, 120, and 155 gallons per capita day (gpcd), respectively. The overall average was 141 gpcd.

These per capita sewage flows show regional patterns, but are different from one region to another. The highest flows are in the northwest arc from Colorado to California; the lowest are in the southwest arc from Arizona to Illinois. The simple state averages in these two arcs are 250 and 89 gpcd, respectively. These figures and the regionalization are based only on the most numerous class, that for populations less than 10,000, and may be different for the total of all population categories.

Statistical analysis shows that there is an upward trend for per capita flows with city population.

Based on the application of the national average gpcd to population served in each population class, the national municipal waste water flow was estimated at 13.8 bgd in 1957.

AVERAGE REMOVALS

A special study was made of the very few cases of sewage treatment plant installations in which sand filters are used in place of secondary treatment. The average fraction of BOD removed for six rapid sand filter entries was 0.51 and for 21 intermittent sand filter entries was 0.77.

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Chapter 3. STREAMS
APPROACHING "COMPLETE" TREATMENT

INTRODUCTION

Advanced waste treatment is expected to be applied, in its pollution control role, to secondary-treatment plant effluent. AWT would probably not be suggested for a stream receiving large quantities of raw sewage or primary effluent. Pollution control authorities impelled to clean up such a stream would probably first recommend primary treatment on the untreated discharges and secondary treatment on the primary discharges. Since the nation as a whole is far from a goal of 100 percent "complete" treatment, i.e., primary plus secondary treatment, in the present stage of development, pursuit toward that goal by conventional treatment is a major activity of pollution control authorities. If, however, there are streams for which a large percentage of the existing discharges are already receiving "complete" conventional treatment, then for these streams pollution control authorities might well suggest AWT as a further pollution control measure.

In 1957 only 41 percent of the sewered communities in the United States had secondary treatment plants[1]. These data and their regional or state breakdowns do not show the extent to which secondary treatment plants may be grouped together on particular streams. The purpose of the study described in this chapter was to determine whether there are any streams in the nation for which a large part of the municipal effluent discharging thereto has received secondary treatment. Also of interest, of course, was the actual number of such streams and their geographical locations. Such streams would constitute prospective areas of application for AWT.

The approach was to compute for each stream an index number measuring the fraction of BOD removed by the existing installations. This index number was taken as the average fraction of BOD removed by each community, weighted by the volume of each discharge actually reaching the stream.

MEANING OF f INDEX NUMBER

The f index number was chosen as a compromise among a number of possible quantities that might measure the approach to "complete" treatment on a stream. Streams with high f index numbers are those for which most of the municipal effluent reaching the stream is already highly treated. Streams with low f index numbers are those for which only a small portion of the discharges are highly treated. From the standpoint of a direct measure of markets, one might use an index representing the percentage of plants having a fraction of BOD removed above some critical value. That value, conventionally, would be 0.9 since this represents roughly the expected fraction removed by secondary treatment plants operated in an exemplary manner. Such a number would not measure the actual influence of the applied treatment on the water quality in the stream. For example, one might find that 8 of 10 plants on a stream had secondary treatment, but the remaining two plants, employing only primary treatment, might represent a very large proportion of the total waste discharge. Thus, to suggest AWT for this stream would be impractical.

The chosen f index number is an attempt to weight the individual fractions removed by the size of the plant. This index number does not quite measure the fraction of the total BOD removed by the existing plants. In part, this comes about because portions of some discharges, such as effluent used for irrigation, do not reach the stream and, therefore, are not reflected in the cumulative index number. Even if there were nonesuch, the index number still does not quite measure the overall fraction of BOD removed. In order to be a precise measure of this quantity, the individual fractions would have to be weighted, not by the volume, but by the pounds of BOD.

A sample study of this discrepancy showed that although theoretically not precise, the cumulative f index is a close approximation to the true fraction of BOD removed. The sample study was composed of tabulations, for Texas and Oregon, of all discharges for which both volume flow and pounds of BOD (in terms of population equivalent) were available. It happened that there were 20 eligible entries in each state. The difference between the f index number and the true average fraction removed was +0.8 percent for Texas and -4.5 percent for Oregon. This indicates that the f index number measures quite well the overall fraction of BOD removed. Actually, this fact is incidental to the main use of the f index in the present study in which it is simply an indicator of the approach to "complete" treatment on a stream.

The detailed procedures by which the f indices were developed are described in chapter 6. In the ideal conventional situations in which all secondary plants have individual f's of 0.9, all primary plants have f's of 0.35, and those without treatment f's of 0.0, a cumulative f of 0.9 would indicate that all discharges along the stream receive secondary treatment. In actual practice, such a sharp cutoff cannot be applied because some plants have known f values that differ from the assumed nominal value. Furthermore, a cumulative f of less than 0.9, say 0.8, might come about through degrading of the 0.9 plants with a moderate percentage of 0.35 plants, or with a small percentage of untreated discharges. Thus, although it has a precise mathematical derivation, a cumulative f value below 0.9 does not have a single, easily definable meaning. Subject to the restrictions implicit in the above concept, however, the cumulative f does have this real meaning, that the closer it is to 0.9, the more likely is the stream a prospect for AWT.

NATURE OF STREAMS

The nature of the entity termed a "stream" is also described in detail in chapter 6. To reduce the study to manageable proportions, only streams having lengths of more than about 100 miles were assessed. At each confluence point of a stream with a main stream, cumulations were made for the tributary and for the main stream above and below the confluence. In addition, if a main stream had a length greater than 200 miles without confluences, an additional accumulation point was placed arbitrarily so that no reach was greater than 100 miles without a cumulation point. At each cumulation point the figures refer to all the upstream discharges.

The results of the cumulations are shown in Table 1 and mapped on Figures 1, 2, and 3. The table is divided into three sections composed of f ranges of 0.900 and up, 0.850 to 0.899, and 0.800 to 0.849.

Table 1. STREAMS APPROACHING "COMPLETE" TREATMENT

Entry No.	Name of accumulation point	State	Lat.-Long. °N °W	f' fraction removed[a]	Upstream recoverable municipal discharge, mgd
1	San Pedro R acw[b]Gila R.	Ariz.	33-110 8	0.930	0.4
2	Purgatone acw Arkansas	Colo.	38-103.2	0.947	5.1
3	Big Sioux R. near Sioux Falls	S. D.	44-98.8	0.919	4.7
4	Pit R. near Lookout	Calif.	41-121	0.900	0.9
5	Feather R. acw Sacramento R.	Calif.	39-122	0.919	5.5
6	Mokelumne acw San Joaquin	Calif.	38-121.6	0.900	4.5
7	Nueces R. near Crystal City	Tex.	28.6-100	0.902	0.4
8	San Antonio R. acw Guadalupe	Tex.	28.4-97	0.966	72.8
9	Guadalupe R. at New Braunfels	Tex.	29.8-98	0.937	0.8
10	Leon R. at Gatesville	Tex.	31.5-98	0.903	0.9
11	Little R. acw Brazos R.	Tex.	31-97	0.906	11.3
12	Mustang Cr. acw Canadian R[c].	Tex.	38.6-102.4	0.900	0.1
13	Des Plaines R. acw Illinois	Ill.	41.4-88.3	0.902	1,305.7
14	Des Moines R. acw E. Des Moines R.	Iowa	43-94	0.978	3.6
15	Raccoon R. acw Des Moines	Iowa	41.6-93.6	0.976	5.1
16	Iowa R. acw Cedar R.	Iowa	41.3-91.3	0.917	24.0
17	Platte R. near Saratoga	Wyo.	41.6-107	0.962	0.4
18	Laramie R. acw N. Platte R.	Wyo.	42.1-104.5	0.902	1.9
19	Grand R. acw Missouri R.	S.D.	45.8-100.6	0.927	0.2
20	Big Sioux R. acw Missouri	S.D.	42.5-96.5	0.906	18.5
21	Arikaree Cr. acw Republican R.	Neb.	40.0-101.5	0.900	0.9

Table 1. STREAMS APPROACHING "COMPLETE" TREATMENT (cont.)

22	Eel R. at Pacific Ocean	Calif.	40.6-124.0	0.902	2.0
23	Salinas R. at Pacific Ocean	Calif.	36.7-122.0	0.909	7.1
24	San Antonio R. at Gulf of Mex.	Tex.	28.4-97	0.909	85.6
25	Santa Rosa acw Gila R.	Ariz.	32.2-112.2	0.862	6.0
26	Arkansas R. acw Cucharas R.	Okla.	38.2-104.2	0.865	32.1
27	N. Canadian acw Canadian R.	Colo.	35.3-95.5	0.885	46.8
28	Powder R. near Broadus	Mont.	45.2-105.6	0.887	0.8
29	San Joaquin acw Modelumne	Calif.	38.0-121.6	0.878	51.1
30	Salt R. acw Brazos R.	Tex.	33.2-100.0	0.857	1.4
31	White R. at Plainview	Tex.	34.0-101.5	0.896	1.2
32	Running Water Cr. near Clovis	Tex.	35.5-102.6	0.890	0.1
33	Colorado R. at LaGrange	Tex.	30.0-97.0	0.872	33.1
34	Brazos R. acw Navasota R.	Tex.	30.3-96.0	0.871	32.6
35	Brazos R. bcw[b] Navasota R.	Tex.	30.3-96.0	0.865	35.9
36	Brazos R. acw Little R.	Tex.	31.0-97.0	0.854	21.0
37	Brazos R. bcw Little R.	Tex.	31.0-97.0	0.869	32.3
38	Canadian R. bcw Mustang R[c].	Tex.	35.5-102.4	0.873	0.2
39	N. Canadian R. at Texhoma[d]	Okla.	36.6-102.0	0.885	0.3
40	N. Canadian R. at Hooker[d]	Okla.	36.8-101.0	0.875	0.7
41	Big Sandy West R. acw Elm R.	Tex.	33.0-97.0	0.862	41.0
42	Elm R. acw Big Sandy West R.	Tex.	33.0-97.0	0.858	5.4
43	Trinity R. bcw Big Sandy & Elm R.	Tex.	33.0-97.0	0.862	46.4
44	Sabine R. near Longview	Tex.	32.4-94.5	0.878	7.3
45	Neches R. acw Angelina R.	Tex.	31.0-94.0	0.858	2.4
46	Illinois R. acw Mississippi	Ill.	39.0-90.5	0.891	1,453.7
47	Illinois R. near Beardstown	Ill.	40.0-90.4	0.892	1,445.3
48	Illinois R. near Peoria	Ill.	41.0-89.5	0.896	1,374.4
49	Illinois R. bcw Des Plaines	Ill.	41.4-88.3	0.898	1,326.5
50	Cedar R. at Waterloo	Iowa	42.4-92.0	0.858	37.2
51	Des Moines R. bcw Raccoon R.	Iowa	41.6-93.6	0.872	18.2
52	Iowa R. bcw Cedar R.	Iowa	41.3-91.3	0.875	63.6
53	Iowa R. acw Mississippi	Iowa	41.0-91.0	0.872	63.8
54	Concho R. acw Colorado	Tex.	31.5-99.2	0.885	0.1
55	Humboldt R.	Nev.	40.6-117.0	0.875	1.3
56	Little Colorado R. acw Colorado	Ariz.	36.0-111.8	0.870	1.6
57	Powder R. acw Yellowstone R.	Mont.	46.7-105.4	0.854	0.8
58	San Juan R. acw Colorado R.	Utah	37.0-111.0	0.866	8.5
59	Osage R. acw Missouri R.	Mo.	38.5-92.0	0.851	32.0
60	Gasconade R. acw Missouri R.	Mo.	38.5-92.0	0.865	0.8
61	Hatchie R. acw Mississippi	Miss.	38.6-90.0	0.875	4.53
62	Calcasieu R. at Gulf of Mex.	La.	30.0-93.3	0.858	11.7
63	Chickasaw R. acw Pascagcoula	Miss.	31.0-88.8	0.853	10.0
64	San Joaquin R. acw Sacramento	Calif.	38.0-122.0	0.880	55.5
65	Colorado R. at Gulf of Mex.	Tex.	28.6-96.0	0.865	35.9
66	Brazos R. at Gulf of Mex.	Tex.	29.0-95.2	0.861	42.1
67	Red Lake R. acw Red R. (into Canada)	Minn.	48.0-97.0	0.877	2.6
68	Neches R. at the Gulf of Mex.	Tex.	30.0-94.0	0.852	27.0
69	Little Wabash acw Wabash R.	Ill.	38.0-88.0	0.871	4.0
70	Scioto R. acw Ohio	Ohio	38.8-83.0	0.885	102.2
71	St. Joseph R. at Lake Michigan	Mich.	42.0-86.0	0.851	73.9
72	Kaskaskia R. acw Mississippi	Ill.	38.0-90.0	0.874	14.8
73	Gila R. acw Santa Rosa	Ariz.	33.2-112.2	0.829	7.0
74	Gila R. bcw Verde R.	Ariz.	33.2-112.3	0.830	7.0
75	Arkansas R. bcw Cucharas R.	Colo.	38.2-104.2	0.822	34.1
76	Arkansas R. acw Purgatone R.	Colo.	38.0-103.2	0.812	38.5
77	Arkansas R. bcw Purgatone R.	Colo.	38.0-103.2	0.825	43.5
78	Arkansas R. acw Sandy Cr.	Colo.	38.2-102.5	0.833	46.3
79	Arkansas R. bcw Sandy Cr.	Colo.	38.2-102.5	0.831	47.4
80	Arkansas R. near Larned	Kans.	38.0-99.0	0.828	51.2
81	Arkansas R. near Wichita	Kans.	38.0-98.0	0.830	61.0
82	Chikaskia R. acw Salt R.	Okla.	36.6-97.2	0.809	3.5
83	Salt R. acw Chikaskia R.	Okla.	36.6-97.2	0.817	1.5
84	Salt R. bcw Chikaskia R.	Okla.	36.6-97.2	0.813	5.1
85	Arkansas R. acw Salt R.	Okla.	36.6-97.2	0.815	106.0
86	Arkansas R. bcw Salt R.	Okla.	36.6-97.2	0.815	111.0
87	Arkansas R. acw Cimarron R.	Okla.	36.0-96.4	0.814	111.7
88	Deep Fork R. acw Canadian R.	Okla.	35.3-95.5	0.814	4.5

Table 1. STREAMS APPROACHING "COMPLETE" TREATMENT (cont.)

89	Osage R. near Osceola	Mo.	38.0-94.0	0.804	12.3
90	White R. acw E.F. White R.	Ind.	38.5-87.2	0.817	147.0
91	White R. bcw E.F. White R.	Ind.	38.5-87.2	0.809	174.3
92	Tuolumne acw San Joaquin	Calif.	37.6-121.2	0.814	13.5
93	Pecos R. near Carlsbad Caverns	N.M.	32.0-104.0	0.845	10.0
94	Pecos R. at Pecos	Tex.	31.4-103.3	0.847	10.0
95	Pecos R. at Rankin	Tex.	31.0-102.0	0.849	10.0
96	Pecos R. acw Rio Grande R.	Tex.	29.8-101.3	0.849	10.0
97	Rio Grande acw Pecos R.	Tex.	29.8-101.3	0.813	48.2
98	Rio Grande bcw Pecos R. (acw Devil R.)	Tex.	29.8-101.3	0.820	58.2
99	Rio Grande bcw Devil R.	Tex.	29.8-101.0	0.819	58.2
100	Rio Grande near Bennett	Tex.	30.6-105.0	0.812	48.2
101	Rio Grande near Redford	Tex.	29.5-104.2	0.813	48.2
102	Rio Grande bcw Maravillas Cr.	Tex.	29.6-102.8	0.813	48.2
103	Rio Grande near Eagle Pass	Tex.	29.0-101.0	0.821	59.3
104	Rio Grande acw Rio Puerco R.	Tex.	34.3-107.0	0.813	27.8
105	Rio Grande at El Paso	Tex.	32.0-106.0	0.812	48.1
106	Arkansas R. near Lakin	Kans.	38.0-101.0	0.830	47.9
107	Elm Fork Red R. acw Red. R.	Okla.	99.0-34.4	0.818	3.6
108	Dogtown & Tule Crs. at Memphis	Tex.	34.6-101.0	0.839	1.0
109	Wichita R. acw Red R.	Tex-Okla.	34.0-98.0	0.848	1.2
110	Washita R. near Clinton	Okla.	35.5-99.0	0.833	1.4
111	Washita R. near Lindsay	Okla.	34.9-97.7	0.810	4.0
112	Washita R. acw Red. R.	Okla.	34.0-97.0	0.810	5.6
113	Red R. acw Little R.	Kans.	33.6-93.9	0.805	56.6
114	Trinity R. near Fairfield	Tex.	32.0-96.0	0.849	147.6
115	Trinity R. near Huntsville	Tex.	31.0-95.5	0.848	149.3
116	Sabine R. near Hemphill	Tex.	31.2-93.8	0.824	10.0
117	Angelina R. acw Neches R.	Tex.	31.0-94.0	0.829	6.9
118	Neches R. bcw Angelina R.	Tex.	31.0-94.0	0.836	9.2
119	Kaskaskia R. near Vandalia	Ill.	39.0-89.0	0.828	3.0
120	Des Moines R. bcw E. Des Moines R.	Iowa	43.0-94.0	0.824	4.3
121	Des Moines acw Raccoon R.	Iowa	41.6-93.6	0.832	13.1
122	Skunk R. acw North Skunk	Iowa	41.0-92.0	0.836	6.5
123	Skunk R. bcw North Skunk	Iowa	41.0-92.0	0.828	7.0
124	Des Moines R. acw Mississippi	Iowa	40.4-91.4	0.804	40.0
125	Salt R. acw Mississippi	Mo.	39.4-91	0.831	3.3
126	Cedar River acw Iowa R.	Iowa	41.3-91.3	0.849	39.6
127	Colorado River acw Llano[d]	Tex.	30.7-98.5	0.811	6.4
128	Colorado River bcw Llano[d]	Tex.	30.7-98.5	0.802	6.9
129	Brazos acw Clear Fork Brazos[c]	Tex.	33-98.7	0.848	2.4
130	Clear Fork Brazos acw Brazos[d]	Tex.	33-98.7	0.801	2.0
131	Brazos R. bcw Clear Fork Brazos[c].	Tex.	33-98.7	0.831	4.5
132	Brazos River near Blum[d]	Tex.	32.1-97.5	0.842	6.4
133	Colorado R. acw San Saba[d]	Tex.	31.2-98.7	0.812	6.3
134	Colorado R. bcw San Saba[d]	Tex.	31.2-98.7	0.810	6.4
135	Double Mountain Fork acw Salt Fork Brazos[c]	Tex.	33.3-100	0.836	0.5
136	Beals Cr. acw Sulphur Springs Creek[c]	Tex.	32.1-101.7	0.819	0.7
137	Beals Cr. bcw Sulphur Springs Creek[c]	Tex.	32.1-101.7	0.830	0.7
138	Concho River acw Colorado[c]	Tex	31.5-99.2	0.885	0.1
139	Colorado River acw with Concho[d]	Tex.	31.5-99.2	0.805	4.3
140	Colorado River bcw Concho[d]	Tex.	31.5-99.2	0.815	4.4
141	Gila River bcw Salt R.	Ariz.	33.4-112.3	0.801	12.3
142	Maumee River at Lake Erie	Mich.	42-83	0.815	115.4
143	Gila River near Montezuma	Ariz.	33-113	0.809	13.5
144	Arkansas R. bcw Cimarron R.	Okla.	36-96.4	0.812	22.5
145	Caney R. acw Verdigris R.	Okla.	36.3-95.6	0.839	2.2
146	Neosha R. acw Arkansas R.	Okla.	35.9-95.2	0.806	29.2
147	Canadian R. bcw Deerfork & North Cr.	Okla.	35.3-95.5	0.813	75.4
148	Wind River near Thermopolis	Wyo.	43.5-108.2	0.830	2.2

Table 1. STREAMS APPROACHING "COMPLETE" TREATMENT (cont.)

149	Marias R. acw Missouri R.	Mont.	48-110.5	0.823	1.4
150	Little Sioux R. acw Missouri	Iowa	42-96	0.812	6.2
151	Lodgepole Cr. acw S. Platte R.	Colo.	41-102.5	0.849	2.6
152	Frenchmans Cr. acw Republican R.	Neb.	40.2-101	0.847	1.4
153	Nodaway R. acw Missouri R.	Mo.	40-95	0.831	1.5
154	Grand R. acw Missouri R.	Mo.	39.4-93.2	0.817	4.4
155	White R. acw Wabash R.	Ind.	38.4-87.8	0.808	174.7
156	Black Water & Yellow R. at Gulf	Fla.	30.5-87	0.842	1.7
157	Satilla R. at Atlantic Ocean	Ga.	31-81.5	0.829	5.5
158	Saluda R. acw Broad R.	S. C.	34-81	0.816	17.1
159	Blackwater & Bannister R. acw Roanoke R.	Va.	36.6-78.8	0.832	18.7
160	Cape Fear R. at Lillington	N.C.	35.4-78.8	0.832	44.5
161	Delaware River at Portland	Pa.	41-75	0.807	14.1
162	Neches R. acw Frio R.	Tex.	28.5-98.2	0.818	0.6
163	Rio Grande at Laredo	Tex.	27.7-99.8	0.821	59.3
164	Red R. acw Sulphur R (bcw Little R.)	Kans.	33.1-93.9	0.801	58.3
165	Trinity R. at Gulf of Mexico	Tex.	30-95	0.847	151.9
166	Sabine R. at Gulf of Mexico	Tex.	30-94	0.818	12.6
167	Mississippi bcw Illinois	Ill.	39-90.5	0.801	2,021.1

[a] $f = \frac{\Sigma Qf + 0.9\Sigma \boxed{Q}}{\Sigma Q + \Sigma \boxed{Q}}$ = f including irrigation-type discharges

Q = mgd reaching stream other than by irrigation
f = fraction BOD removed
$\boxed{Q}$ = mgd reaching stream through irrigation.

[b] acw = above confluence with
bcw = below confluence with

[c] For these accumulation points the fraction, P, of the flow resulting from irrigation type contributions is in the range of 0.5 to 0.84. Where P was > 0.84, accumulation point was omitted from the table P $\Sigma \boxed{Q} / (\Sigma Q + \Sigma \boxed{Q})$.

[d] For these accumulation points P is in the range 0.2 to 0.5. For points without footnote c or d, P is negligible.

In each section of Table 1 the entries are divided into two parts. The first part in each section lists watersheds for which the accumulation point is also incorporated in some accumulation point in the following parts of the table. To illustrate, an accumulation point that appears in the first part of the 0.9-and-over section may also contribute to an accumulation point appearing in the second part of the 0.90 section, or in either the 0.85 or the 0.80 sections. In the second part of each section are those accumulation points that do not form part of any basin listed elsewhere in the table.

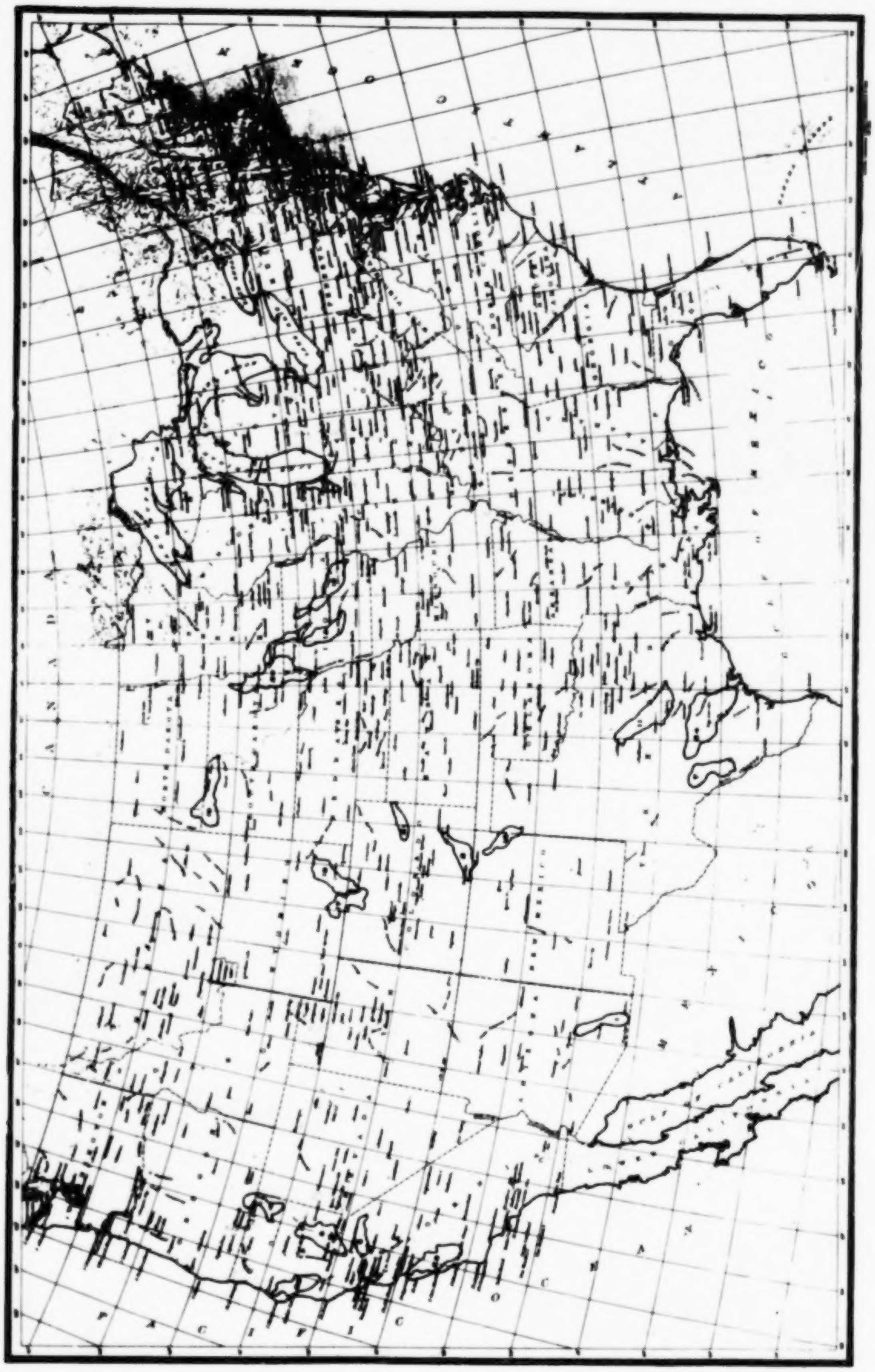

Figure 1. Streams approaching "complete" treatment - f' > 0.90.

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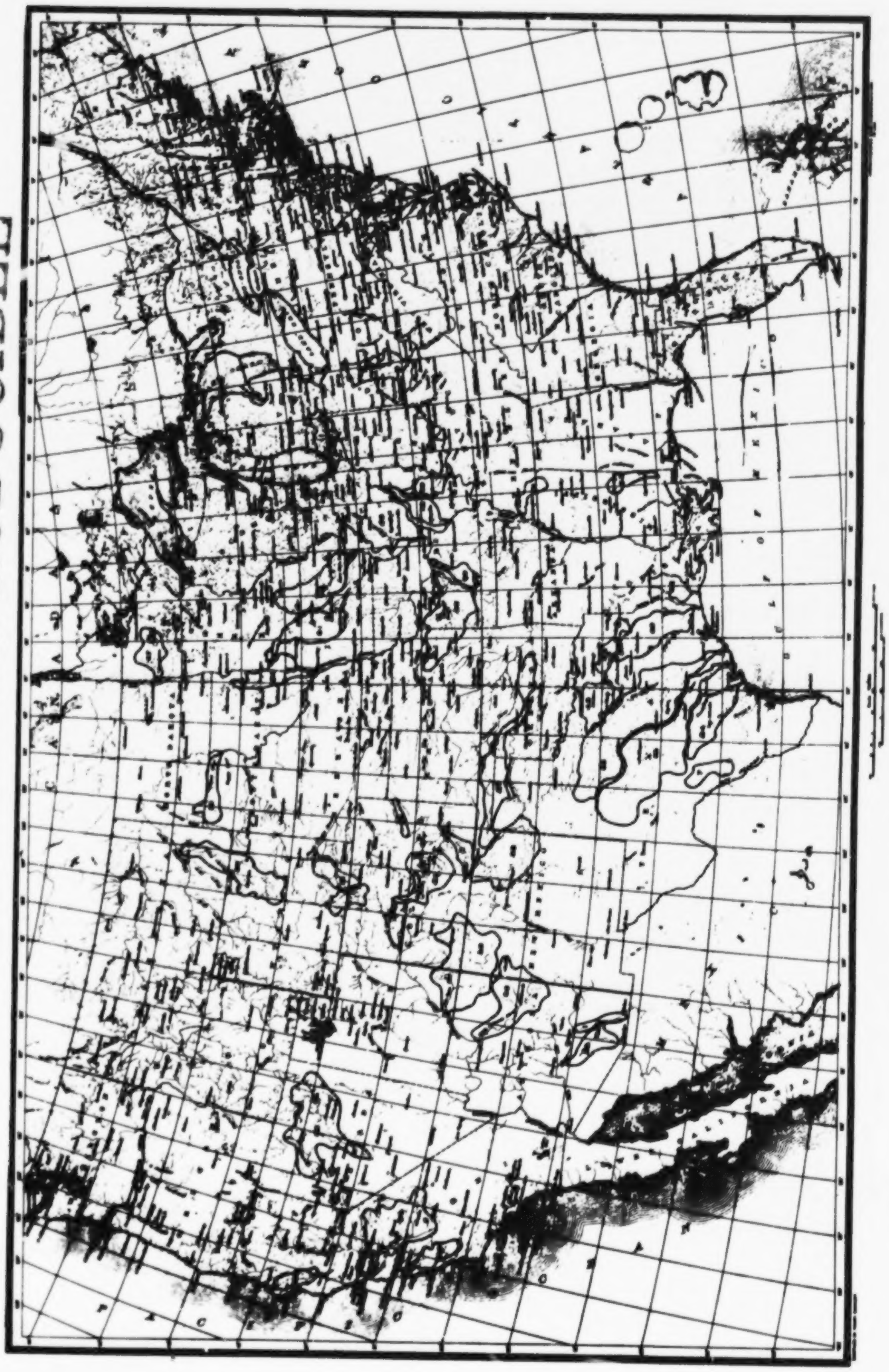

Figure 2. Streams approaching "complete" treatment - f' > 0.85.

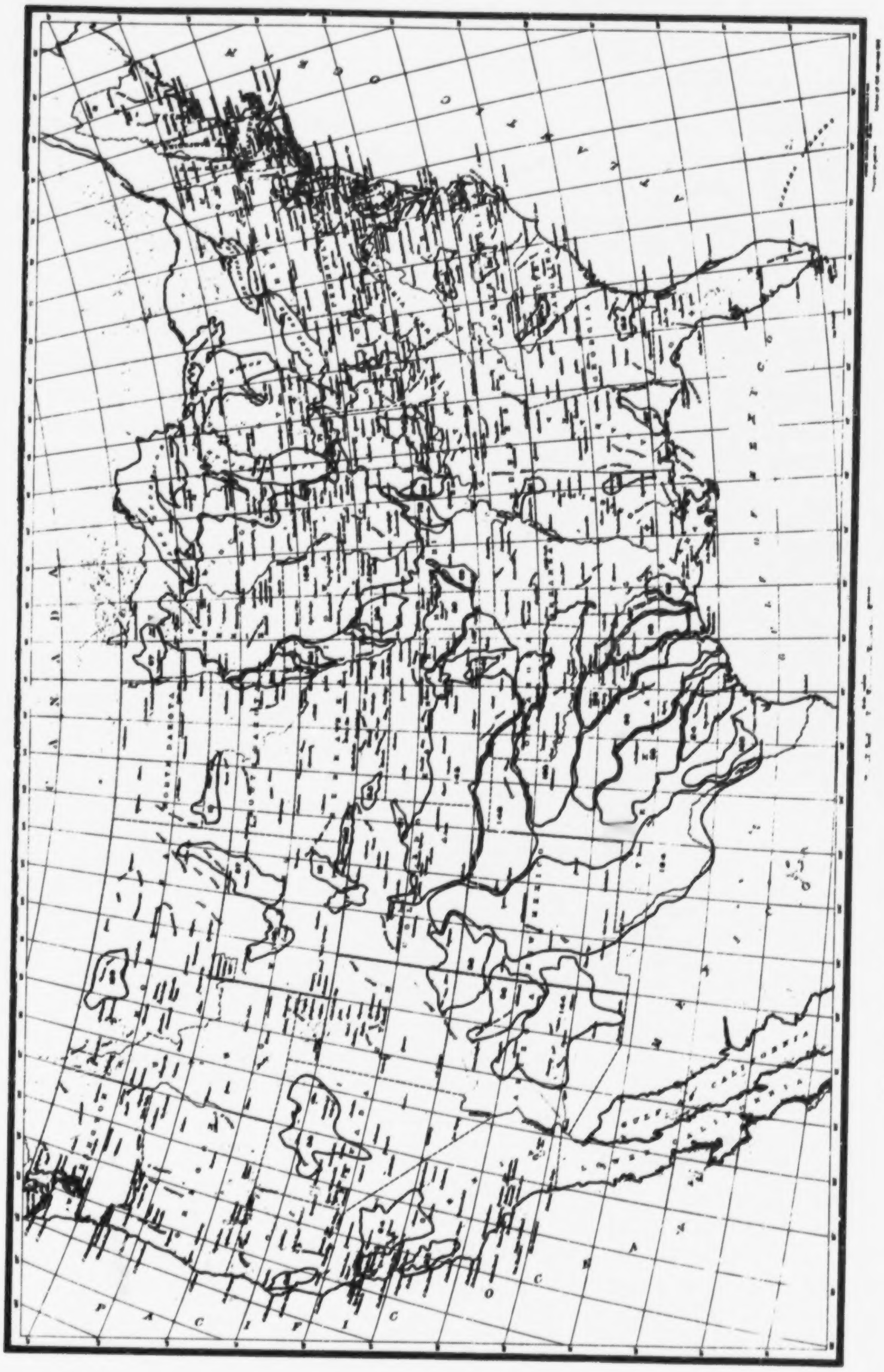

Figure 3. Streams approaching "complete" treatment - f' > 0.80.

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RESULTS

Number of Entries

Table 2 summarizes the data on number of entries in Table 1. About 3 percent of the eligible accumulation points have cumulative f's of 0.90 or over. This percentage is not a direct measure of the "number of streams approaching complete treatment" because of the complex role of the confluence points. If at a confluence point, the main stream and also the tributary have f's above 0.9, the f at the accumulation point below the confluence must also be 0.9 or over. But in that case, three accumulation points in the 0.9 category would be counted while actually only two basins are involved. If either the main stream or the tributary has an f above 0.9 while the other f is below, the accumulation point below the confluence may be 0.9 or it may not be. If it is not, the number of accumulation points above 0.9 would correspond to the number of basins. If it is, two accumulation points representing essentially only one basin were counted. A better measure of the number of basins approaching complete treatment is obtained by eliminating the "below the confluence" accumulation point both from the tally and from the total. When this is done, as in the last two columns of Table 2, the percent of "basins" in the 0.9-and-over class becomes 4.0 percent.

Table 2. SUMMARY OF ACCUMULATION POINTS BY f CATEGORY

f'[a]	Eligibles[b]	No. of accumulation points	% of eligible points	No. accumulation points less bcw's	% of basins
0.80 and over		167	21.1		
0.85 and over		72	9.0	65	10.8
0.90 and over		24	3.1	24	4.0
	Single	219			
	Triple	191			
	Total	792	100	601	

[a] f' is the fraction removed including the irrigation-type discharges.

[b] Eligibles are accumulation points other than map boundary points, etc. Single eligibles are accumulation points having a single accumulation. Triple eligibles are the accumulation points at confluences having three accumulations.

Although the above is a correct measure for the percentage of basins, it is too low for the percentage of "streams", i.e., 100-mile stream segments because each accumulation point on a main stream refers to discharges not only from the 100-mile segment immediately above it, but also from all other upstream segments.

To determine the number of such upstream segments above each accumulation point for which f > 0.9 would involve a considerable amount of work, not justified by the results to be gained. A better picture of the totality of eligible streams is obtained from the maps and from the basin land areas as presented in Table 3.

Table 3. TOTAL LAND AREAS OF BASINS BY CATEGORY

f	% of national area
0. 90 and over	2. 2
0. 85 and over	9. 8
0. 80 and over	ca 30^x

The basins in the 0.90-and-over category comprise 2.2 percent of the conterminous United States area of about 3 million square miles.

Geography

The three maps in Figures 1, 2, and 3 show the locations of the stream basins with cumulative f's of 0.90 and over, 0.85 and over, and 0.80 and over, respectively. The numbers on the indicated basins correspond with the entry numbers in Table 1.

Not all of the 24 accumulation points for f = 0.9 and over in Table 1 are shown on the map because some of them are incorporated in larger basins in the same f category. For example, entry No. 24, the San Antonio River below its confluence with the Guadalupe, incorporates the individual basins of the Guadalupe River and the San Antonio River above their confluence, portions of which are also in the 0.9-and-over class.

The 20 mapped areas on Figure 1 are those stream basins in which the municipal discharges are now receiving essentially "complete" treatment, and thus, by the philosophy of this study, are those in which conventional treatment could not compete with advanced waste treatment for further pollution control.

Only one of the 20 basins lies east of the Mississippi River. This should not be taken as a reflection on the pollution control activities east of the Mississippi River. From the standpoint of clean streams, many streams in the East (as well as in the West) do not appear on the map, not because they have some untreated discharges or primary treatment, but simply because there are no municipal discharges at all to these streams. Also, most streams in the West, where the population density is low, have a comparatively small number of municipal discharges per stream and thus, the greater probability that these will approach "complete" treatment.

Finally, the preponderance of mapped areas in the West cannot be directly related to advanced waste treatment markets, at least in terms of flow volume. As will be shown in a following paragraph, a major portion of the total discharge in the 0.90-and-over class comes from the one watershed east of the Mississippi, namely the DesPlaines River, which takes the discharge from Chicago.

Volume of Discharge

Table 4 shows the total nonduplicating recoverable discharge flow in each f index range. In cumulating this figure, care was taken to exclude upstream tributaries so that their discharges would not be counted twice. The table shows the total discharge, which, by the philosophy of this study, is not excluded from the potential AWT market at present. The volume of effluent for f above 0.90 is 1.48 bgd and for f above 0.85 is 2.23 bgd (this, of course, includes the 1.48 bgd from the higher f category). This 1.48 bgd is 14.5 percent of the nation's total municipal discharge reaching surface streams (excluding small coastal basins).

Table 4. TOTAL RECOVERABLE DISCHARGE BY f CATEGORY

f'[a]	ΣQ,[b] bgd	% of nation's total municipal discharge	No. of non-duplicating basins
> 0.90	1.48	14.5	20
> 0.85	2.23	21.9	38
> 0.80	3.51	34.5	53

[a] f' is the weighted fraction removed and includes irrigation returns.

[b] Recoverable discharge reaching streams.

Table 5 shows the total discharges of interest by region. It is seen that the 1.48 bgd in the f $\geq$ 0.9 category is made up of 22.6 percent of the total municipal waste discharged to the Western Gulf basins and 27.8 percent of the total municipal waste discharge to the Mississippi Basin. To be clear as to the meaning of these figures, for the Western Gulf region it means that of all the recoverable discharge reaching streams in the Western Gulf region, 22.6 percent occurs to individual streams or stream reaches for which f is 0.9 or over.

Table 5. TOTAL DISCHARGE BY f CATEGORY AND REGION

Region	Total waste, mgd	$f \geq 0.9$, mgd	%	$f > 0.85$, mgd	%
Western Gulf	430.7	97.4	22.6	208.8	48.5
Mississippi	4,913.3	1,365.3	27.8	1,698.4	34.6
Colo.-Calif. column	449.2	20.3	4.5	82.3	18.3
East-South	2,655.4	0	0	9.9	0.37
Great Lakes	1,694.7	0	0	176.1	10.4
TOTAL[a]	10,170.6	1,483.0	14.5	2,175.5	21.9

[a] Total includes slight additional sources from Red River of the North and excludes small coastal basins.

Major Contribution Cities

A special study was made of the accumulation points in the nation above f = 0.80 that had cumulative discharges above 100 mgd. This analysis was made to determine the extent to which such discharges came from individual cities. The results are shown in Table 6. At least for these 100-mgd-and-over accumulation points, a relatively few cities contribute the major portion of the total discharge.

Of the 1.48 bgd in the f=0.9 -and-over category in Table 4, the city of Chicago contributes 1.26 bgd, or about 85 percent. The next largest individual city contributor in the 0.9-and-over class is San Antonio, with a discharge of 70 mgd.

Table 6. ACCUMULATION POINTS IN NATION ABOVE f=0.80 WITH CUMULATIVE DISCHARGES GREATER THAN 100 mgd-MAJOR CONTRIBUTING CITIES

Accumulation point, city	Q, f> 0.8, mgd	No. of major cities	% of total discharge from major cities
Arkansas bcw[a] Cimarron R.	122.5	3	43.2
Colo. Springs	6.5		
Pueblo	16.0		
Wichita	30.4		
White acw[b] Wabash R.	174.6	2	66.8
Indianapolis	96.8		
Muncie	20.0		
Trinity R. at Gulf	151.9	2	78.0
Fort Worth	37.4		
Dallas	81.0		
Scioto acw Ohio R.	102.2	1	80.2
Columbus	82.0		
Maumee R. at Lake Erie	115.3	2	80.3
Fort Wayne	24.9		
Toledo	55.4		
Mississippi bcw Illinois R.	2,021.1		
Chicago	1,263.2	1	62.5
Waterloo	21.0		
Des Moines	16.7		
Cedar Rapids	13.0		
Davenport	12.0		
Minneapolis	145.0	9	12.6
Kenosha	15.4		
Madison	22.0		
Meenah	10.0		
Racine	19.5		

[a] bcw = below confluence with.

[b] acw = above confluence with.

CONCLUSIONS

To attain a higher degree of pollution control for the vast majority of the nation's streams, conventional treatment rather than AWT should be applied. A small percentage of the nation's streams (100 miles long and over) already receive as high a degree of treatment as can be reached with conventional means. For these streams, over 4 percent of all U.S. streams, the next step in achieving a higher degree of pollution source control would be AWT. The total discharge involved is 1.48 bgd, or about 15 percent of the national total recoverable discharge; 1.26 bgd of this flows from the single city of Chicago. If an accumulated fraction of BOD removed of 0.85 rather than 0.90 is taken as appropriate for the imminent potential application of advanced waste treatment, the percentage of U.S. streams involved would be over 11 percent and the discharge about 2.2 bgd (about 22 percent of the nation's recoverable discharge).

The reader is cautioned that many other factors enter into the determination of the market for advanced waste treatment. Prominent among these, of course, is the total cost of advanced waste treatment as compared with the benefits to be achieved by the higher degree of pollution control. Benefits are also achieved in advanced waste treatment by augmentation of water supply, but the above analysis is concerned only with the pollution control aspect as a determinant of the market.

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Chapter 4. UPSTREAM MUNICIPAL WASTES IN SURFACE WATER SOURCES

INTRODUCTION

The literature in recent years contains a number of references to the higher degree of reuse of water in various river basins and to the increasing degree of reuse, which the future must bring. Statements frequently quoted but difficult to track to their original source are that Ohio River water is reused six times at periods of low flow and the Verdigris River water in Kansas is reused 17 times from source to mouth. Such figures are obtained by taking the total withdrawal from the river and dividing it by some minimum streamflow figure. Thus, in the above quotations, the ratio of total water withdrawn to minimum streamflow would be 6 and 17, respectively.

The two major purposes of withdrawals in the nation are for irrigation and for industrial purposes, the former predominating in the West, the latter in the East. Of the total industrial withdrawals, something like three-quarters is for cooling, which for the most part returns water to the stream with very little degradation in quality.

The sixfold figure for the Ohio River has recently been adequately controverted by the actual data,[2] which show that at Cincinnati the ratio of cumulative upstream withdrawals for all municipal or industrial uses except cooling to the drought flow is about 0.16. When the withdrawals for cooling are included, the ratio becomes 2.71 at Cincinnati. In this case the drought flow is defined as that likely to occur 1 out of 120 months, which, for the Ohio River, is about 10 percent of the average flow.

Such figures and such studies are of interest in advanced waste treatment for two reasons. First, advanced waste treatment in its ultimate application contemplates direct reuse of municipal or industrial waste waters. The impetus to advanced waste treatment in its pollution control aspects arises from the known facts that a certain degree of reuse now occurs, that the degree of reuse will inevitably increase in the future, and that conventional treatment processes do not remove all of the contaminants prior to voluntary or involuntary, recognized or unrecognized reuse. Thus, it is of interest to know the present degree and extent to which surface waters contain used waters from upstream. Public knowledge that water is reused now will be a psychological advantage when more direct reuse becomes necessary.

With these purposes in mind, including both the technical and the psychological aspects, the studies outlined in this chapter were undertaken to determine just how much upstream municipal waste discharges generally are to be found in the surface water supply of cities.

It should be clearly recognized that unlike the studies or quotations previously referred to, the present study is concerned only with the municipal waste discharges upstream. Industrial waste discharges were not included partly because they do not play a great part in the psychological hurdle, but mostly because data on industrial waste discharges are not readily available. Nationwide, industrial withdrawal is about 14 times municipal withdrawal, and approximately the same ratio should apply to the waste discharges, including industrial cooling water. This ratio, of course, does not hold for each individual stream, but, on the average, the percentage of total upstream used water will be about 15 times those reported here for upstream municipal waste waters.

It should also be recognized that there is a difference between the reuse factors mentioned in this introduction and the data developed by the present study. The "reuse factors" conventionally used are not precisely reuse factors because they refer to the total amount of water withdrawn rather than the total amount returned to the stream. Obviously reuse must be measured by the water returned to the stream and is not influenced by water not returned to the stream. For a uniform type of use, e.g., irrigation or municipal having a constant return ratio, that is, ratio of water returned to water withdrawn, the true (return) reuse factor will be the withdrawal "reuse factor" times the return ratio. Thus for a stream involving only municipal discharges where the return ratio is of the order of 0.8, the return reuse factor will be 80 percent of the withdrawal reuse factor. On an overall average the return ratio for industrial use is also about 0.8, and so this ratio would apply for combined industrial and municipal use along a stream. If, however, the withdrawal is largely for irrigation purposes, the return ratio will be of the order of 0.2; and in that case the return reuse factor will be only 20 percent of the withdrawal reuse factor. The above relations apply regardless of the number of actual withdrawal points and regardless of any natural increments to the stream in the reach under consideration.

METHOD

The detailed procedures by which the data were collected and handled are described in chapter 6. A total of 155 municipalities having over 25,000 in population and a surface water source were selected for study. The average streamflow in Water Year 1961 (Oct. 1960-Sept. 1961) past the intake was determined from gaging-station records. The low flow is, in general, higher than commonly used figures for drought flow. The concept of drought flow is arbitrary, both with regard to the drought duration, i.e., whether the minimum day, the minimum week, the minimum month, etc., and also with regard to recurrence interval, i.e., whether the indicated drought is to be expected once in 10 years, once in 100 years, etc. The minimum flow month in 1961 is realistic in that the available municipal discharge figures used also apply to 1961, although for the calendar year rather than the water year. The percentages computed thus show the actual percentages for the average flow and for the minimum monthly flow for 1961. Of course, not only the streamflow, but also the municipal discharges have a seasonal variation, but the extent of this seasonal variation is not known and could not be incorporated in this national study.

The average annual cumulated upstream municipal waste discharges were obtained for each of the selected cities by the methods described in chapter 6. The fractions computed were the ratios of these cumulative upstream discharges to the 1961 average flow and to the 1961 minimum month flow near each city.

A complicating telescoping effect was not taken into account in the present study, partly because the definition thereof is very difficult and partly because the data are not available. To explain, the waste discharged by an upstream city is mixed with the streamflow before that streamflow is picked up by the next downstream city. Thus, the discharge from the second city includes some water that has already been discharged by the first upstream city. Some of the individual molecules of water in the discharge from the second city, therefore, have already been counted as discharge from the upstream city. The total amount of water that has been through one or more sewage systems upstream is, thus, somewhat less than the sum of the discharges reported here. In effect, the present procedure weights the correct nonduplicating sum by the number of uses and reuses upstream. In terms of the contaminants carried by the discharges, therefore, the present procedure is a preferable measure; however, to avoid misunderstanding, it should be clearly understood that the waste volumes used here are the sums of the upstream discharges.

RESULTS

Table 7 shows the results for the selected cities. The gaging station used in the computation and its approximate distance from the center of the city's river front are given.

Table 7. FRACTION OF UPSTREAM MUNICIPAL DISCHARGES IN MUNICIPAL SOURCES

Entry	Name of city	State	Source river	Gaging station	Distance gaging station to city, straight-line miles	Cumulative municipal discharge, mgd	Percent municipal waste in water supply stream: In low flow	Percent municipal waste in water supply stream: In avg flow	Population served
1	Topeka	Kans.	Kansas	Kansas R. at Topeka	0	44.8	4.16	0.938	135,000
2	Lawrence	Kans.	Kansas	Kansas R. at Lecompton	11	45.5	4.04	0.837	29,000
3	St. Joseph	Mo.	Missouri	Missouri R. at St. Joseph	0	116.4	4.49	2.00	92,000
4	Kansas City	Mo.	Missouri	Missouri R. at Kansas City	0	671.3	6.59	2.36	650,000
5	Jefferson City	Mo.	Missouri	Mo. R. at Boonville & Saline Cr.	35	674.8	5.73	1.80	32,000
6	St. Cloud	Minn.	Mississippi	Mississippi near Royalton[a]	24	10.5	1.94	0.781	34,000
7	Minneapolis	Minn.	Mississippi	Mississippi R. near Anoka	5	13.4	1.35	0.659	570,000
8	Ft. Collins	Colo.	Cache La-Poudre	Cache La Poudre R. near Ft. Collins [d]	5	0.5	2.85	0.191	25,027
9	Greeley	Colo.	Cache La-Poudre	Cache La Poudre R. near Ft. Collins [d]	5	0.5	2.85	0.191	40,000
10	Denver	Colo.	S. Platte	S. Platte R. at Denver	0	8.8	17.1	5.27	612,000[e]
11	Englewood	Colo.	S. Platte	S. Platte R. at Denver	5	4.3	8.29	2.56	38,000
12	Bismarck	N.D.	Missouri	Missouri R. at Bismarck	0	65.3	1.08	0.629	27,670
13	Council Bluffs	Iowa	Missouri	Missouri R. at Omaha, Neb.	7	187.8	2.90	1.28	55,000
14	Omaha	Neb.	Missouri	Missouri R. at Omaha	0	48.4	2.29	1.01	335,000
15	Great Falls	Mont.	Missouri	Missouri R. near Great Falls	10	12.8	0.558	0.420	68,000
16	Billings	Mont.	Yellowstone	Yellowstone R. at Billings	0	3.6	0.382	0.122	62,380
17	Bartlesville	Okla.	Caney at Hulah	Caney at Hulah[b]	14	0.1	1.03	0.0178	32,000
			Caney at Bart.	Caney at Oche Lata	8	0.8	3.21	0.0682	
18	Joplin	Mo.	Shoal Cr.	Shoal Cr. above Joplin	4	0.8	1.49	0.322	46,300
19	Ft. Smith	Ark	Clear Cr.		-	0.	0[c]	0[c]	87,000
20	Muskogee	Okla.	Neosho	Neosho near Ft. Gibson Res.	1	29.7	3.30	0.344	44,000
21	Pueblo	Colo.	Arkansas	Arkansas R. near Pueblo	7.5	6.0	4.26	1.60	115,000
22	Farmington	N.M.	Animas	Animas R. at Farmington	0.	2.4	1.75	0.547	25,000
23	Tacoma	Wash.	Green	Green R. at Tukwila	12	0.2	0.121	0.0155	170,000
24	Everett	Wash.	Sultan	Sultan R. near Startup	20	0.2	0.330	0.0387	66,500
25	Longview	Wash.	Cowlitz	Cowlitz R. at Castle Rock[a]	6	0.4	0.0248	0.00465	29,600
26	Portland	Ore.	Bull Run	Bull Run R. near Bull Run	0[f]	0.2	0.391	0.0341	560,582
27	Salem	Ore.	N. Santiam	N. Santiam R. at Mehama	19	0.0	0.00234	0.00076	56,926

Table 7. FRACTION OF UPSTREAM MUNICIPAL DISCHARGES IN MUNICIPAL SOURCES (continued)

Entry	Name of city	State	Source river	Gaging station	Distance gaging station to city, straight-line miles	Cumulative municipal discharge, mgd	Percent municipal waste in water supply stream		Population served
							In low flow	In avg flow	
28	Engene	Ore.	McKenzie	McKenzie R. near Coburg	3	0	0	0	71.000
29	Santa Rosa	Calif.	Russian	Russian R. near Guerneville	9	0	0	0	37, 200
30	San Angelo	Tex.	Concho	Concho R. near San Angelo	2	0. 2	7. 36	0. 732	60, 500
31	Austin	Tex.	Colorado	Colorado R. at Austin	0	11. 4	2. 96	0. 707	216, 000
32	Beaumont	Tex.	Neches	Neches at Evadale[a]	21	10. 4	0. 823	0 133	123, 000
33	Shreveport	La.	Cross Lake	PawPaw Bayou near Greenwood[d]	15	0. 01	0. 946	0. 0111	185, 000
34	Grand Forks	N. D.	Red	Red R. North of Grand Forks	0	13. 1	6. 02	1. 72	34, 000
35	Fargo	N. D.	Red	Red R. North of Fargo	0	4. 0	6. 60	1. 86	46, 000
36	Kansas City	Kans.	Missouri	Missouri R. at Kansas City	0	197. 9	4. 88	1. 75	128, 840
37	Minot	N. D.	Souris	Souris R. above Minot	3. 5	0. 3	4. 03	1. 74	30, 000
38	Helena	Mont.	Ten Mile Cr.	Ten Mile Cr. near Rimini	17	0	0	0	25, 000
39	Eureka	Calif.	Mad	Mad R. near Arcata	11	0. 1	0. 423	0. 0093	28, 000
40	Danville	Va.	Dan	Dan R. at Danville	0	8. 9	1. 60	0. 592	50, 000
41	Highpoint	N. C.	Deep			0	0[c]	0[c]	29, 000
42	Greensboro	N. C.	Reedy Fork Cr.	Reedy Fork Cr. near Gibonville	15	0. 1	0. 341	0. 0808	125, 000
		N. C.	Haw River	Haw River at Haw River[b]	7	14. 0	15. 1	4. 23	32, 000
43	Burlington	N. C.	Stoney Cr.		-	0	0[c]	0[c]	-
44	Goldsboro	N. C.	Little	Little R. near Princeton	15	0. 6	1. 77	0. 333	30, 000
45	Wilson	N. C.	Contenea	Contenea R. near Hookerton	30	0. 1	0. 150	0. 0232	31, 000
46	Rocky Mount	N. C.	Tar	Tar R. near Nashville	5	2. 9	2. 68	0. 618	34, 000
47	Wilmington	N. C.	Cape Fear	NE Cape Fear R. near Chinguapin[a]	38	56. 1	4. 05	1. 22	55, 000
48	Charlotte	N. C.	Catawba	Catawba R. at Catawba, S. C.	21	38. 3	4. 31	2. 48	215, 000
49	Rockhill	S. C.	Catawba	Catawba R. near Rockhill	5	23. 4	1. 49	0. 832	38, 000
50	Greenville	S. C.	Saluda	Saluda R. near Greenville	4. 6	0. 7	0. 214	0. 133	175, 000
51	Columbia	S. C.	Broad	Broad R. at Richtex	15	12. 7	0. 595	0. 284	165, 000
52	Anderson	S. C.	Rocky&Black	Rocky R. near Calhoun Falls[c]	28	0	0[c]	0[c]	45, 000
53	Augusta	Ga.	Savannah	Savannah R. at Augusta	0	11. 9	0. 315	0. 208	160, 000
54	Macon	Ga.	Ocmulgee	Ocmulgee R. at Macon	0	11. 5	2. 06	0. 569	120, 000
55	Tampa	Fla.	Hillsborough	Hillsborough R. near Tampa	5. 5	7. 3	2. 31	0. 522	285, 000
56	Atlanta	Ga.	Chattahoochee	Chattahoochee R. near Atlanta	0	5. 6	0. 555	0. 298	610, 000

Table 7. FRACTION OF UPSTREAM MUNICIPAL DISCHARGES IN MUNICIPAL SOURCES (continued)

Entry	Name of city	State	Source river	Gaging station	Distance gaging station to city, straight-line miles	Cumulative municipal discharge, mgd	Percent municipal waste in water supply stream		Population served
							In low flow	In avg flow	
57	La Grange	Ga.	Chattahoochee	Chattahoochee R. at W. Point	19	97.2	4.94	2.43	25,000
58	East Point	Ga.	Sweetwater Cr.	Sweetwater Cr. near Austell	6	0.2	0.322	0.0853	44,235
59	Columbus	Ga.	Chattahoochee	Chattahoochee R. at Columbus	0	104.2	4.55	2.03	150,000
60	Rome	Ga.	Oostanawla	Oostanawla R. near Rome	4.5	1.0	0.157	0.0434	50,000
61	Anniston	Ala.	Coldwater Sp.	Coldwater Springs near Anniston	7	0	0	0.	55,000
62	Gadsden	Ala.	Coosa	Coosa R. at Gadsden	0	10.3	0.491	0.158	80,000
63	Jackson	Miss	Pearl	Pearl R. at Jackson	0	3.6	1.46	0.127	144,422
64	Vicksburg	Miss	Mississippi	Mississippi R. near Vicksburg	1	4708.8	3.39	1.25	32,000
65	Little Rock	Ark.	Arkansas R	Arkansas R. at Little Rock	0	289.1	3.89	0.829	220,000
66	Louisville	Ky.	Ohio	Ohio R. at Louisville	0	7600.7	7.73	0.969	115,467
67	Evansville	Ind.	Ohio	Ohio R. at Evansville	0	857.1	7.64	0.908	155,000
68	Bowling Green	Ky.	Barren	Barren R. at Bowling Green	0	3.5	2.77	0.226	33,000
69	Nashville	Tenn.	Cumberland	Cumberland R. below Old Hickory[a]	12	16.8	0.338	0.129	315,000
70	Lexington	Ky.	Kentucky	Kentucky R. near Winchester	3	4.0	2.04	0.102	120,000
71	Charleston	W. Va.	Elk-Kanawha	Kanawha R. at Charleston	0	19.7	0.933	0.215	119,000
72	Cincinnati	Ohio	Ohio	Ohio R. at Cincinnati	0	561.3	6.66	0.845	825,000
73	Portsmouth	Ohio	Ohio	Ohio R. near Maysville, Ky.	45	420.2	5.18	0.693	60,000
74	Columbus	Ohio	Scioto	Scioto R. at Columbus	0	4.7	5.39	0.546	593,964
75	Huntington	W. Va.	Ohio	Ohio R. at Huntington	0	398.7	2.73	0.804	118,092
76	Ashland	Ky.	Ohio	Ohio R. at Ashland	0	411.5	1.26	0.177	45,000
77	Oak Ridge	Tenn.	Clinch	Clinch R. near Searboro	3	15.3	0.876	0.530	28,000
78	Chattanooga	Tenn.	Tennessee	Tennessee R. at Chattanooga	0	101.1	0.643	0.446	225,000
79	Kingsport	Tenn.	Holston	S. Fork Holston at Kingsport	0	20.3	2.36	1.37	45,000
80	Knoxville	Tenn.	Tennessee	Tennessee R. at Knoxville	0	43.6	0.798	0.496	175,000
81	Ft. Wayne	Ind.	St. Joseph	St. Joseph R. at Cedarville	10	4.3	9.78	1.39	169,000
82	Appleton	Wis.	Fox	Fox. R. at Rapide Croche Dam	15	30.0	2.14	1.10	48,000
83	Kirkwood	Mo.	Meramec	Meramec R. near Eureka	11	2.2	0.676	0.101	25,000
84	St. Louis	Mo.	Mississippi	Mississippi R. at St. Louis	0	750.6	7.04	2.56	
				Missouri R. at Herman	49	723.1	5.02	1.41	870,000
85	Kankakee	Ill.	Kankakee	Kankakee R. at Momonee[a]	10	11.3	2.12	0.651	52,000
86	Cedar Rapids	Iowa	Cedar	Cedar R. at Cedar Rapids	0	38.7	6.97	1.64	90,000

Table 7. FRACTION OF UPSTREAM MUNICIPAL DISCHARGES IN MUNICIPAL SOURCES (continued)

Entry	Name of city	State	Source river	Gaging station	Distance gaging station to city, straight-line miles	Cumulative municipal discharge, mgd	Percent municipal waste in water supply stream		Population served
							In low flow	In avg flow	
87	Iowa City	Iowa	Iowa	Iowa R. at Iowa City	0	20.4	10.7	1.83	37,000
88	Ottumwa	Iowa	Des Moines	Des Moines R. at Ottumwa	0	39.7	11.2	1.11	39,000
89	Burlington	Iowa	Mississippi	Mississippi R. at Keokuk	--	481.5	2.82	1.38	35,400
90	Davenport	Iowa	Mississippi	Mississippi at Clinton[a]	25	311.6	2.56	1.27	104,000
91	St. Paul	Minn.	Mississippi	Mississippi R. near Anoka	5	184.1	18.5	9.05	350,000
92	Hagerstown	Md.	Potomac	Potomac R. at Hancock	25	16.5	4.11	0.603	53,000
93	Rockville	Md.	Potomac	Potomac R. near Wash., D.C.	5	52.4	3.86	0.688	25,000
94	Petersburg	Va.	Appomattox	Appomattox R. near Petersburg	6	1.0	1.40	0.126	50,000
95	Richmond	Va.	James	James R. near Richmond	1	26.6	2.00	0.654	303,000
96	Akron	Ohio	Cuyahoga	Cuyahoga R. at Old Portage	6	0	0	0	330,000
97	Alliance	Ohio	Mahoning	Mahoning R. at Alliance	0	0.8	17.4	1.85	35,850
98	Newark	Ohio	Licking	Licking R. near Newark	3.5	0.8	2.12	0.234	45,500
99	Ann Arbor	Mich.	Huron	Huron R. at Ann Arbor	0	1.4	1.39	0.634	68,000
100	Flint	Mich.	Flint	Flint R. near Flint	2	1.6	2.48	0.739	200,000
101	Grand Rapids	Mich.	Grand Rapids	Grand Rapids R. at Grand Rapids	0	46.4	6.28	3.31	200,000
102	Washington	Pa.	Chartiers Cr.	Chartiers Cr. at Carnegie	18	0.7	2.41	0.406	41,000
103	Beaver Falls	Pa.	Beaver	Beaver R. at Beaver Falls	0	57.9	16.6	2.96	35,000
104	Durham	N.C.	Michie Lake	Flat R. at Bahama[d]	6	0.4	2.03	0.431	92,000
105	Bloomington	Ill.	Lake Bloomington	Money Cr. near Towande	8	0	0	0	40,000
106	Alton	Ill.	Mississippi	Mississippi R. at Alton	0	2,023.7	8.76	3.74	62,875
107	Rock Island	Ill.	Mississippi	Mississippi R. at Clinton, Iowa[a]	27	311.6	2.56	1.27	51,780
108	Moline	Ill.	Mississippi	Mississippi R. at Clinton, Iowa[a]	24	299.4	2.46	1.22	43,000
109	Granite City	Ill.	Mississippi	Mississippi R. at St. Louis, Mo.	4	2,750.7	7.04	2.56	65,000
110	Tulsa	Okla.	Spavinaw Lake	Spavinaw Cr. near Row[d]	0[f]	0.9	-	0.907	295,000
111	Providence	R.I.	N. Pawtuxet	Pawtuxet R. at Cranston	7	7.1	8.56	2.20	383,134
112	Lawrence	Mass.	Merrimack	Merrimack R. at Lowell	7	61.3	5.10	1.39	70,933
113	Auburn	N.Y.	Owasco Lake	Owasco Lake outlet near Auburn[d]	4	0.5	5.32	0.271	35,249
114	Rome	N.Y.	Fish Cr.	E. Branch Fish Cr. at Taberg	10	0.3	0.589	0.116	44,000
115	Watertown	N.Y.	Black	Black R. at Watertown	0	2.2	0.290	0.115	38,000

Table 7. FRACTION OF UPSTREAM MUNICIPAL DISCHARGES IN MUNICIPAL SOURCES (continued)

Entry	Name of city	State	Source river	Gaging station	Distance gaging station to city, straight-line miles	Cumulative municipal discharge, mgd	Percent municipal waste in water supply stream		Population served
							In low flow	In avg flow	
116	Poughkeepsie	N.Y.	Hudson	Hudson R. at Green Island	78	131.9	4.39	1.49	55,000
117	Baltimore	Md.	Potapsco	Potapsco R. at Rollofield	9	0.4	1.83	0.493	930,000
118	Binghampton	N.Y.	Susquehanna	Susquehanna R. at Vestal	6	6.3	0.839	0.155	87,000
119	Niagara	N.Y.	Niagara	Niagara R. at Buffalo	14	1,562.8	1.34	0.921	101,000
120	N. Tonawanda	N.Y.	Niagara	Niagara R. at Buffalo	10	1,562.8	1.34	0.921	31,500
121	Tonawanda	N.Y.	Niagara	Niagara R. at Buffalo	4	1,540.3	1.32	1.17	100,000
122	Wilmington	Dela.	BrandywineCr.	Brandywine Cr. at Wilmington	0	3.8	3.22	1.03	156,100
123	Easton	Pa.	Delaware	Delaware R. at Reigelsville, N.J.	8	0.8	0.0263	0.0108	58,000
124	Pottstown	Pa.	Schuylkill	Schuylkill R. at Pottstown	0	21.9	5.21	1.94	32,000
125	Norristown	Pa.	Schuylkill	Schuylkill R. at Philadelphia	14	33.4	4.68	1.80	70,000
126	Trenton	N.J.	Delaware	Delaware R. at Trenton	0	4.5	0.166	0.0651	180,000
127	Philadelphia	Pa.	Schuylkill	Schuylkill R. at Philadelphia	0	40.9	5.73	2.22	2,250,000
128	York	Pa.	Codorus Cr.	Codorus Cr. near York	2	3.5	6.63	1.95	108,750
			Conestoga	Conestoga at Lancaster	0	1.8	1.67	0.614	
129	Lancaster	Pa.	Susquehanna	Susquehanna R. at Marietta	14	177.3	3.38	0.783	100,000
130	Lebanon	Pa.	Fishing & Suntown	Swatora Cr. at Harbor Tavern	9	0.1	0.0481	0.0140	50,000
			Clark Cr.	Clark Cr. near Carson	17	0	0	0	
131	Harrisburg	Pa.	Susquehanna	Susquehanna R. at Harrisburg	0	129.1	3.12	0.628	111,000
132	Camphill	Pa.	Yellow Breeches	Yellow Breeches Cr. near Camphill	1	1.4	1.97	0.778	55,000
133	Warren	Ohio	Mosquito Res.	Mosquito Cr. below Mosquito Cr. Dam[d]	6	0	0	0	70,000
134	Sharon	Pa.	Shenango	Shenango R. at Sharpsville	4	2.1	3.54	0.566	58,500
135	New Kensington	Pa.	Allegheny	Allegheny R. at Watrona	6	71.7	7.36	0.678	43,000
136	S. Pittsburgh	Pa.	Monongahela	Monongahela R. at Braddock	8	44.7	3.98	0.501	47,600
137	Pittsburgh	Pa.	Allegheny	Allegheny R. at Watrona	19	79.0	4.76	0.738	650,000
138	Steubenville	Ohio	Ohio	Ohio R. at Sewickley[a]	28	216.6	9.08	0.955	44,048
139	Weirton	W. Va.	Ohio	Ohio R. at Sewickley, Pa.[a]	28	215.9	9.05	0.952	32,832
140	Clarksburg	W. Va.	W. Fork	West Fork R. at Clarksburg	0	0.8	2.60	0.197	33,812
141	East Liverpool	Ohio	Ohio	Ohio R. at Sewickley[a]	21	211.2	8.90	0.936	28,638

Table 7. FRACTION OF UPSTREAM MUNICIPAL DISCHARGES IN MUNICIPAL SOURCES (continued)

Entry	Name of city	State	Source river	Gaging station	Distance gaging station to city, straight-line miles	Cumulative municipal discharge, mgd	Percent municipal waste in water supply stream		Population served
							In low flow	In avg flow	
142	Fairmount	W. Va.	Tygart Valley	Tygart Valley R. at Colfax	6	2.5	0.919	0.124	51,148
143	Morgantown	W. Va.	Monongahela	Monongahela R. at Lock 15, Hoult	10	7.5	1.90	0.248	36,000
144	Phenix City	Ala.	Chattahoochee	Chattahoochee R. at Columbus	5	104.2	4.56	2.03	32,000
145	Decatur	Ala.	Tennessee	Tennessee R. at Whitesburg	27	122.4	0.589	0.418	29,000
146	E. St. Louis	Ill.	Mississippi	Mississippi R. at St. Louis	1	2,984.7	7.64	2.77	170,000
147	New Albany	Ind.	Ohio	Ohio R. at Louisville	4	755.2	7.69	0.963	37,940
148	Terre Haute	Ind.	Wabash	Wabash R. at Terre Haute	0	96.1	10.6	1.47	81,000
149	Paducah	Ky.	Ohio	Ohio R. at Matropolis, Ill.	8	1,188.9	2.32	0.653	53,000
150	Newport	Ky.	Ohio	Ohio R. at Cincinnati	5	554.4	6.57	0.835	56,000
151	Covington	Ky.	Ohio	Ohio R. at Cincinnati	5	554.4	6.57	0.835	90,000
152	Bossier City	La.	Red	Red R. at Shreveport	5	63.4	1.07	0.363	33,500
153	Monroe	La.	Ouachita	Ouachita R. at Monroe	0	17.8	0.769	0.142	65,000
154	Yakima	Wash.	Naches	Naches R. near Naches	17	2.0	0.648	0.155	13,800
155	Elmira	N.Y.	Chemung	Chemung R. at Chemung	9	5.8	4.20	0.347	70,000

[a] Flow adjusted for tributary entering stream after gaging station and before city.

[b] Two sources of supply.

[c] Total waste flow is 0 thus percent is 0 regardless of flow in stream.

[d] Lake or reservoir source. Low-flow figure generally not applicable.

[e] Population served not accurate for source given because of other sources used.

[f] Distance between gaging station and pipeline intake.

Population Served

Figure 4 shows the distribution of population served in the selected cities according to the percent of upstream municipal discharges present in the low flow. These totals for population served are not the totals for the nation, but only for the sample. The sample consisted only of cities of over 25,000 population. There are 414 such U.S. cities having surface water supplies, but only 155 of them had the necessary data available.

In 1958 the population served by surface sources in cities under 25,000 was 13.5 million and in cities over 25,000 was 61.9 million.[3] In 1962 the population served by surface water in cities over 25,000 remained at 61.9 million; the total population served in the sample of 155 cities, however, is only 21.1 million.[4] The sample thus includes 38 percent of the cities of over 25,000 having surface water supplies and 34 percent of the population served in such cities.

Figure 4 indicates that the median for the study sample is 3.5 percent upstream municipal waste in the low flow in the stream. This means that in the sample of 155 cities having a total population of 21.1 million, for 50 percent of that population, or 10.5 million people, the percent municipal discharge in the low flow was greater than 3.5 percent and for the other 50 percent, it was less than 3.5 percent. For about 6 percent of the population served, the percent municipal waste in the low flow was over 10 percent. In simple terms, 3.5 percent signifies that for the median population, of every 30 gallons of water flowing through its intake during the low flow month of 1961, 1 gallon had passed through a municipal sewerage system upstream.

Figure 5 shows a similar frequency distribution by number of cities rather than by population served. The median here is 2.40, percent, and about 4.5 percent of the cities have an amount of municipal waste in their low flow greater than 10 percent.

In this study the degree of treatment that the 1 gallon of waste water had received was not directly investigated. It may have received no treatment at all, in which case the 1 gallon represents the equivalent of the waste materials that were present in 1 gallon of the raw sewage. At the other extreme, it may have received complete treatment (i.e., a 90 percent BOD removal), in which case the 1 gallon represents the inorganic wastes in 1 gallon of sewage and the organic wastes in 0.1 gallon of sewage. In contemplating this simplification, it should be remembered that the organics present in the completely treated effluent are not identical with those present in the raw sewage, the nominal 0.9 removal efficiency representing a selective removal of those organics which are amenable to conventional treatment.

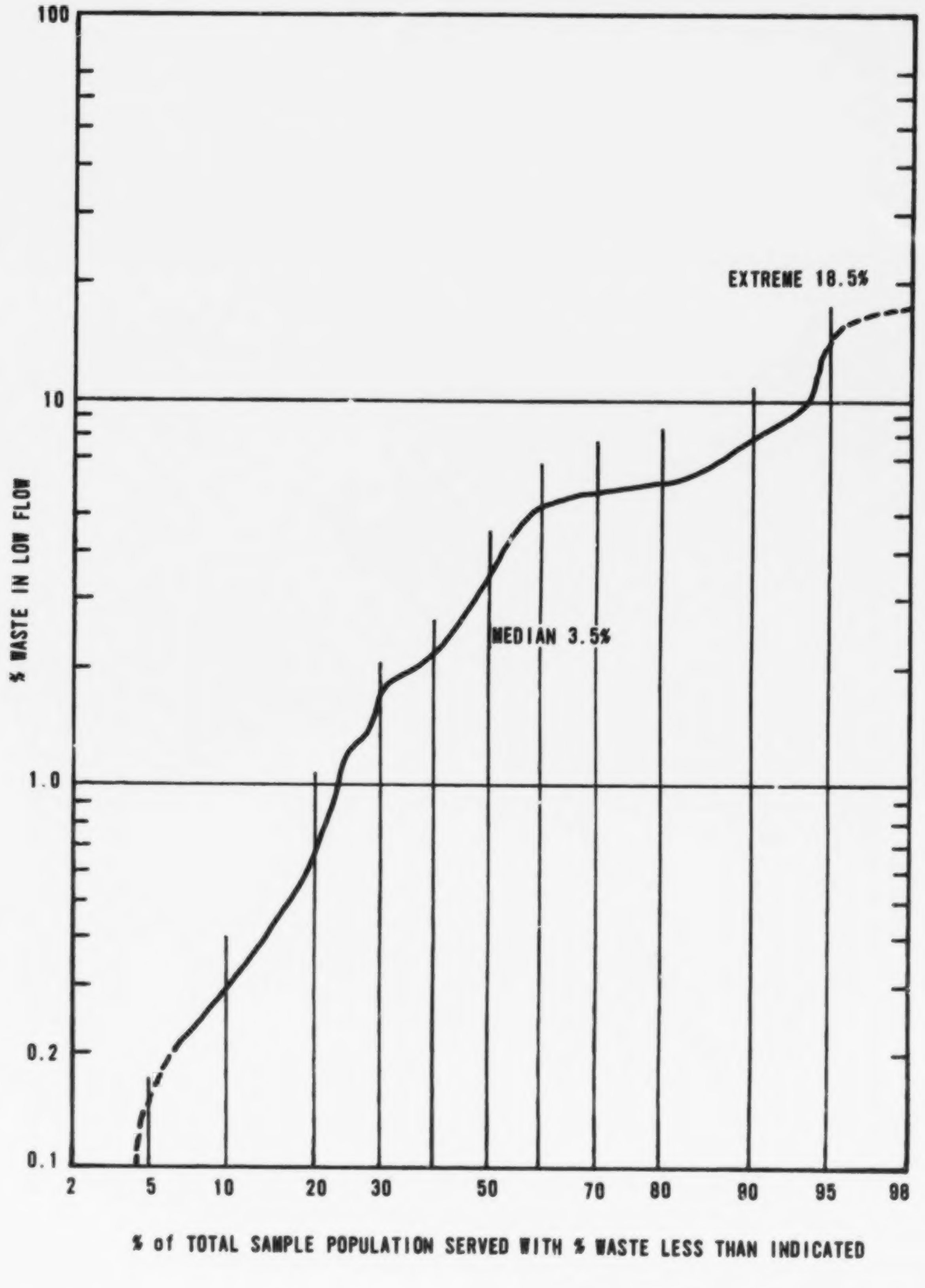

Figure 4. Distribution of population served by percent of waste in low flow.

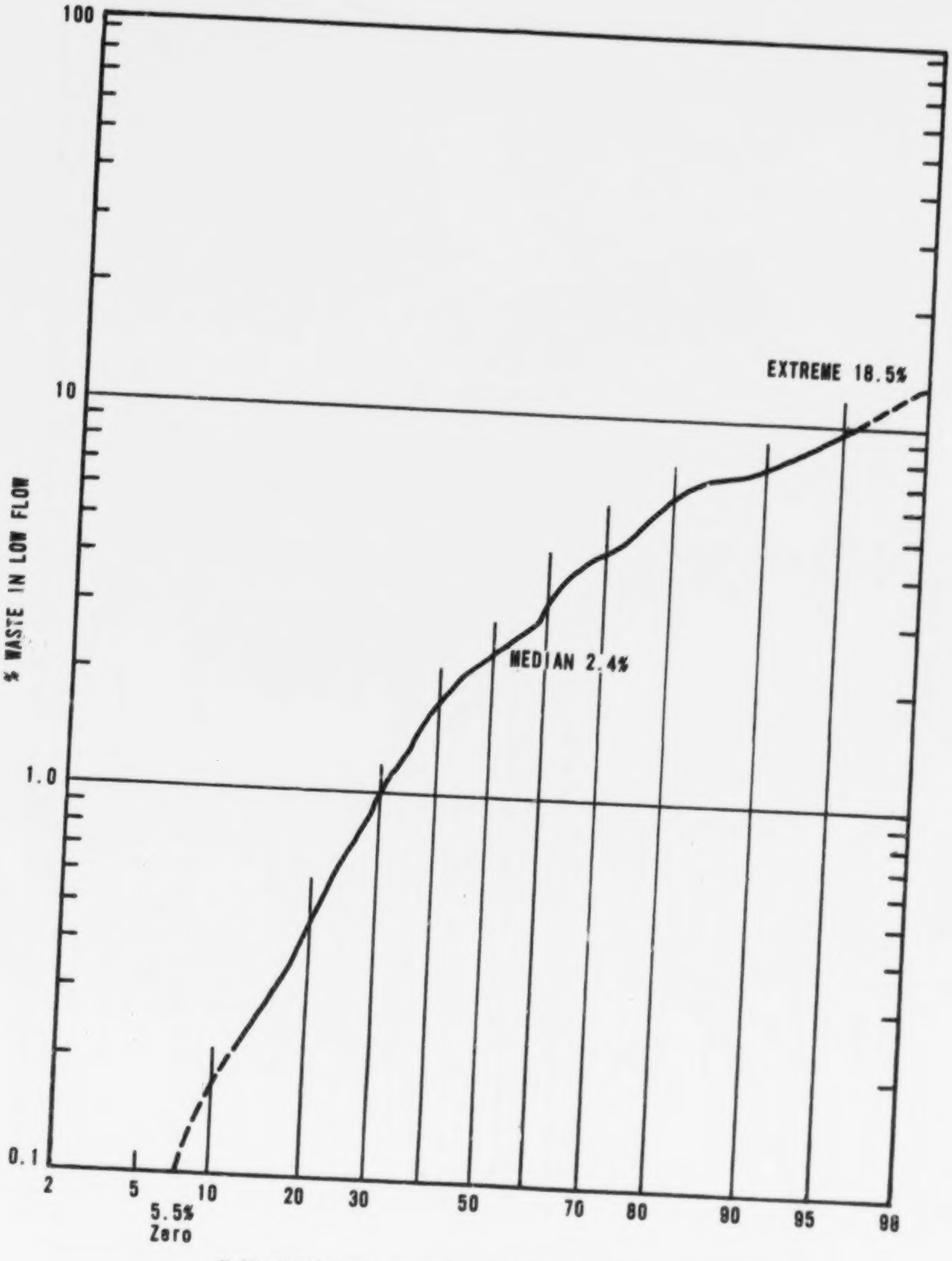

Figure 5. Frequency distribution of cities by percent in low flow.

CONCLUSIONS

Based on samples representing 38 percent of the United States cities having a surface water supply and 34 percent of the population served by these cities, the range of upstream municipal waste water present in the low flow near the city is from 0 to over 18 percent with a median based on the number of cities at 2.40 percent and based on population served at 3.5 percent. This means that for the median population, each 30 gallons of water flowing through the intake during the low-flow month contains 1 gallon of water that has passed through the sewerage system of an upstream community.

If the national average ratio of industrial to municipal water withdrawals (approximately 14:1) were applied to waste ratios present at each municipal intake, the median reuse factor, including both municipal and industrial water, would be of the order of 0.5 and, for the worst cases in the sample, of the order of 3.0.

Chapter 5. IMPACT OF ADVANCED WASTE TREATMENT ON NATIONAL ECONOMY

INTRODUCTION

Exploring the AWT concept for logistical imbalances in the national economy is desirable because the effect of AWT on national life could potentially be great. In the present study, however, only certain aspects of the consumptions of materials and services arising out of AWT are explored. The purpose is to determine whether widespread use of AWT might strain the economy by requiring exhorbitant quantities of certain resources or services. The resources explored are fuel, electric power, chemicals, and certain aspects of ultimate disposal.

DISTRIBUTION OF MUNICIPAL WASTE FLOWS BY VOLUME

The unit consumptions of fuel, electric energy, etc., can sometimes be expected to vary, not only with type of process, but also with production rate or capability of the installation. In order to take this variation into account in summing the total national consumption of resources, it was necessary to know the distribution of waste flows by volume of individual installations.

To do this, data from the 1957 Inventory of Municipal Waste Facilities were utilized. (The corresponding statistical summary for the 1962 inventory was not yet available at the time of writing.) This reference provides data excerpted in Table 8 for the 11,131 sewered communities in the nation from the 1957 inventory. These data were manipulated according to the columns and notes of Table 8 to produce the cumulative frequency distribution shown in columns 7, 8, and 9.

Of the total waste flow accumulated, about 8.11 bgd, or 58.6 percent, was found in the single class of population served of greater than 100,000. To develop the distribution for this large open-end class, use was made of the data on the water supply of the nation's 100 largest cities from reference 5. These data concern water use rather than sewage flow, but for the present purposes, these were assumed to be proportional. The 100 cities were tallied by population served category, and the total in each class was summed to obtain column 2. The smallest of the 100 cities had a population of 128, 000; thus, the lowest size class did not start at 100,000, i.e., the cut off point of the study, in the top portion of Table 8. This was remedied by estimating the missing 100,000 to 128,000 class as described in footnote d. These

Table 8. DISTRIBUTION OF U.S. MUNICIPAL WASTE WATER FLOWS BY VOLUME CATEGORY

1 Population class (thousands)	2 Population served (millions)	3 % of sewered communities	4 No. of sewered communities[a]	5 PC, national,[b] gpcd	6 Total flow in class,[c] mgd	7 Avg flow,[d] mgd/community	8 Class boundaries, mgd/community	9 Cumulative distribution of flows, % less than upper class boundary
< 0.5	0.368	11.3	1258	131	48		< 0.066	0.35
0.5-1	1.207	17.6	1959	131	158	0.080	0.066-0.131	1.49
1-5	9.590	46.8	5209	131	1256	0.251	0.131-0.655	10.57
5-10	7.266	11.4	1269	131	952	0.750	0.655-1.31	17.45
10-25	11.128	8.0	890	120	1335	1.500	1.20 -3.00	27.10
25-50	8.044	2.7	300	120	965	3.218	3.00 -6.00	34.08
50-100	8.446	1.2	133	120	1013	7.620	6.00 -1200	41.40
> 100	52.309	1.0	111	155	8109	73.044	> 15.5	100.00
TOTAL	98.361	100.0	11,131		13,836	1.243		
< 150	1.206		9			f	g	h
100-150[e]	3.2		27	155		15.5	13.0 -19.3	44.40
150-300	7.309		37	155		25.8	19.5 -38.0	51.28
300-500	7.187		20	155		46.7	41.0 -63.4	58.05
500-1000	14.294		22	155		84.6	65.1 -112.8	71.50
1,000-2,000	7.972		6	155		172.9	130 -218	79.00
2,000-4,000	9.539		4	155		310.3	260 -401	87.98
>4,000	12.773		2	155		831.4	576 -1087	100.00
TOTAL	62.281		118					

[a] Column 3 x total of 11,131.

[b] From data in chapter 6.

[c] Column 2 x column 5.

[d] Column 6 ÷ column 4.

[e] The < 150 class boundaries were 128-148. Estimate is based on the assumption that No. of communities in the 100-128 class is 2 x No. in 128-150 class.

[f] Average population in class x 155 gpcd x 52.309/62.281.

[g] Low and high population in class x 155 gpcd x 52.309/62.281.

[h] Cumulative %'s of flow in > 100 population classes were adjusted to total 58.60%, which is the % over all classes represented by the > 100 class from upper portion of table.

adjusted figures indicated a population served of 62.281 million, whereas the sewage flow study had only 52.309 million. A proportional adjustment was made as in footnote e. The average and class boundaries were computed by application of the per capita flows, PC's, to the actual populations in the population class, not to the conventional class boundaries in column 1.

The results shown in column 9 are plotted in Figure 6 to give a cumulative frequency distribution of percent of the nation's total flow of municipal waste water produced in plants less than the indicated size. The indicated size of "plant" is expressed as flow (mgd) per community. Some communities, especially the larger ones, have more than one collection and/or treatment facility; accordingly, the curve would be somewhat displaced downward, especially in the high flow range, if it were expressed in flow per facility.

The distribution curve passing through the top of each class indicates, for example, that 50 percent of the nation's municipal waste water production occurs from plants that treat less than 35 mgd. This is not to be confused with the frequency distribution for number of communities. The median, plant by number, would correspond to a much lower flow. Indeed, as shown in column 7, the average waste flow per community is only about 1.24 mgd. Communities having waste flows greater than 100 mgd contribute about 32 percent of the total U. S. flow. Communities having flows less than about 4 mgd contribute another 30 percent.

Economic Model For Study

On the basis of Figure 6, an economic model was chosen for study of the possible effect of AWT on the economy. The model consisted of the application of AWT to each of the approximately 11,000 sewered communities now in existence and assumed a size distribution equal to the real distribution as read from Figure 6.

Certainly, by the time that AWT would be applied on all sewered communities, the number of sewered communities and the population concerned would be greater than it is now. Thus, when and if the model becomes a reality, the amount of AWT would be greater than here computed. Since the purpose of the study is to compare consumptions for AWT with corresponding national consumptions and productions, this can best be done in terms of the current year or historical data rather than by extrapolating both sets of data into the indefinite future.

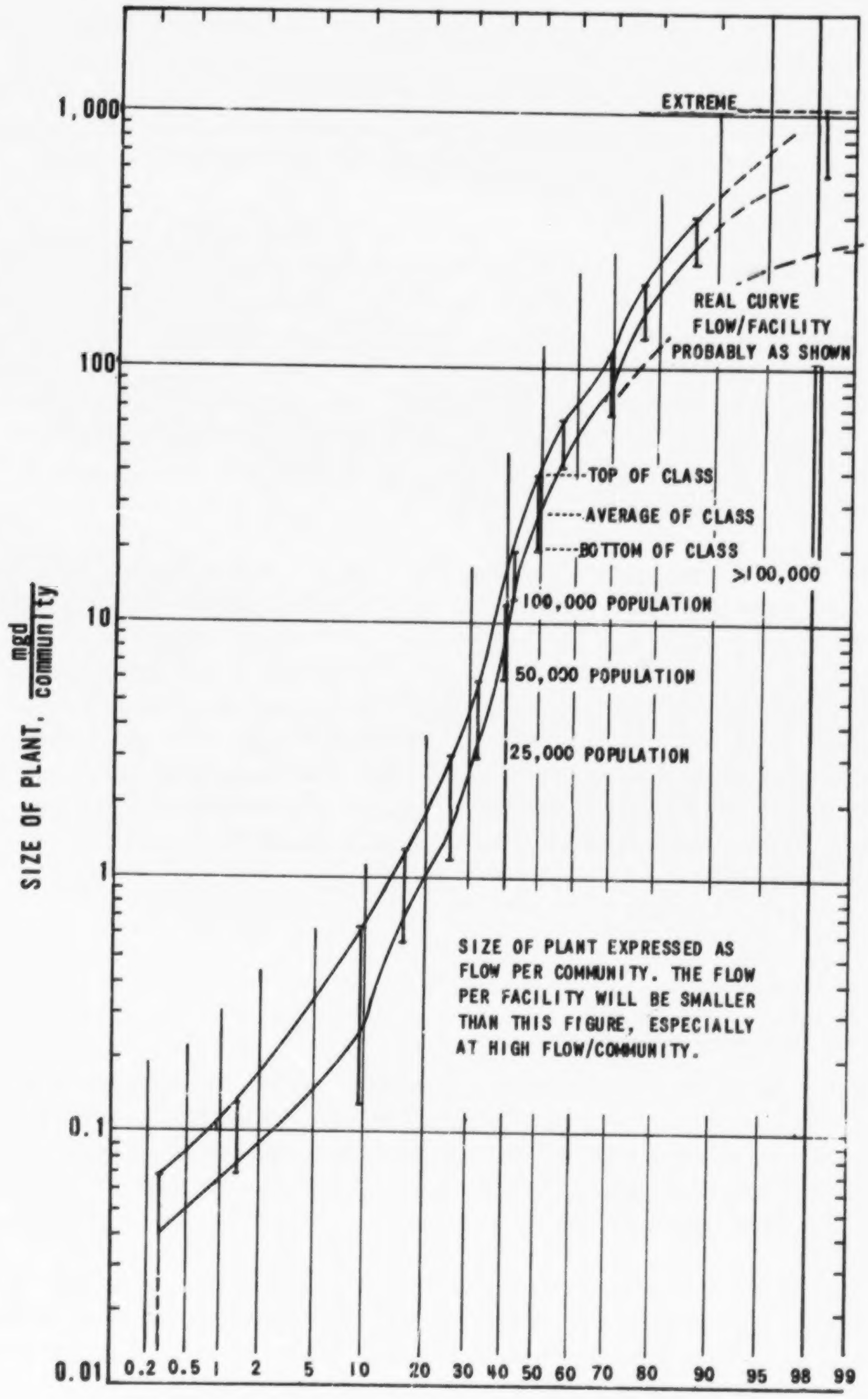

Figure 6. Distribution of U.S. waste water flows by size of plant.

The characteristics of the model are as shown in Table 9.

Table 9. ECONOMY MODEL OF AWT PLANTS

Size of plant, mgd	% of total flow	Total flow treated, mgd
< 0.1	3	450
0.1-1.0	18	2,700
1-10	23	3,450
10-100	31	4,650
100-800	25	3,750
Total		15,000

The total waste flow of the model has been rounded to 15 bgd.

As will be shown in the next section, the first use of the model made it apparent that the consumptions relative to national productions were to be so small that the additional accuracy obtained by applying varying unit consumptions to the selected distribution would be of no significance.

CONSUMPTIONS IN AWT BY DISTILLATION-ADSORPTION SYSTEMS

Unit Consumptions in Distillation

Unit consumptions for distillation were obtained from recent work under the AWTR Activities[6,7]. The unit consumptions are shown in Table 10.

Table 10. UNIT CONSUMPTIONS BY DISTILLATION

	Production, mgd			
	0.1	1	10	100
Fuel, 1,000 Btu/1,000 gal evaporator feed	1,230	690	750	600[a]
Power, kwh/1,000 gal evaporator feed	0.7	0.7	0.7	0.7[a]
H_2SO_4, lb 66° Be' acid/1,000 gal evaporator feed[b]	2.2	2.2	2.2	2.2

[a] Estimated by Louis Koenig - Research.

[b] USPHS estimate based on expected average HCO_3 level.

Unit Consumptions in Adsorption

An adsorption-distillation flow sheet for AWT was developed in which part of the feed (waste water) is evaporated and part is treated with activated carbon. The following data supplied by the AWTR Activities represent the present estimates of carbon use in adsorption and organic carryover in evaporator condensate. The evaporator condensate, assumed to have 5 ppm of organic content, is also treated by adsorption. It is assumed in both cases that adsorption removes 90 percent of the organics and that a capacity of 0.3 pound organic matter per pound of carbon is achieved in the main adsorber and 0.1 pound organic per pound of carbon is reached in the condensate polisher. This amounts to a total dosage of 0.77 (say 0.8) pound of carbon per thousand gallons when the feed contains 50 ppm organics. The carbon loss is predicted to be approximately 6 percent per regeneration cycle. The unit consumptions and flows are shown in Table 11.

Table 11. UNIT CONSUMPTIONS BY ADSORPTION-DISTILLATION

Total product water	0.947 gal/gal AWT feed
Volume evaporator feed	0.525 gal/gal AWT feed
Volume to main adsorber feed	0.475 gal/gal AWT feed
Volume condensate	0.472 gal/gal AWT feed
Carbon makeup	0.048 lb/1,000 gal AWT feed
66% Be' H_2SO_4	1.15 lb/1,000 gal AWT feed

Fuel

When the ratios in Table 11 are applied to the economic model and interpolated figures for fuel consumption per 1,000 gallons are taken from Table 10, the total fuel consumption for the 15-bgd model is 6.6 X 10^{12} Btu/day. The total U.S. energy consumption in 1958[3,[illegible]], was 113 X 10^{12} Btu/day. Accordingly, the fuel used for AWT by adsorption-distillation systems applied to all sewered communities corresponds to 5.8 percent of the nation's total energy use. Since the growth rate in national energy use is about 3 percent per year, the AWT use corresponds to about 2 years' growth.

Electric Energy

In addition to the 0.7 kwh/1,000 gallons used in the evaporator section, some electric energy will be needed for pumping in the two adsorption stages. Pumping water through a 40-psi pressure drop requires about 0.4 kwh/1,000 gallons. Pressure drops as high as 40 psi with granular carbon adsorbent are unlikely, and the estimate is conservatively high. The composite is 0.73 kwh/1,000 gallons of process feed, which, applied to the model, gives 11.0 X 10^6 kwh/day.

The total electrical generation of the nation[9] is about 2.7 X 10^9 kwh/day; therefore, the electrical energy required for the AWT model is only 0.4 percent of the total electric generation.

Chemicals

The 2.2 pounds of H_2SO_4 per 1,000 gallons of evaporator feed applied to the 15-bgd model gives a consumption of 8,700 tons per day of 66° Be' H_2SO_4. U.S. production of 100 percent equivalent H_2SO_4 in 1962 was 119.117 X 10^6 tons,[10] corresponding to 352,000 tons/day of 66° Be' acid (93.2%). Thus the consumption for the model would be 2.5 percent of U.S. production.

The 0.048 pound of carbon per 1,000 gallons calls for 360 tons/day of activated carbon. The total national production of activated carbon in 1962 was 169 tons/day[11]. Thus, full-scale application of AWT by adsorption-distillation would increase the activated-carbon consumption 113 percent over the present consumption.

The water and waste treatment industries together used 24,000 tons of activated carbon in 1957,[12] and one may estimate that this figure was approximately 28,000 tons in 1962, corresponding approximately to 74 tons/day. Even if this 74 tons/day were dispensed with by complete application by AWT, there still would remain a requirement for 286 tons/day, which is still a 69 percent increase over the present production.

From the above computation it is apparent that full-scale application of adsorption-distillation AWT would have little effect on fuel, electric energy, or sulfuric acid production, but would have a major effect on the activated carbon industry.

CONSUMPTIONS IN AWT BY ADSORPTION-ELECTRODIALYSIS SYSTEMS

Adsorption-Electrodialysis Flow Sheet

An alternative system for AWT application is adsorption-electrodialysis. The basis is a flow sheet in which adsorption is applied to all the feed, followed by single-stage electrodialysis. The feed organic concentration, carbon capacity, etc., are the same as those for the main adsorber of the adsorption-distillation flow sheet, and a carbon dose of 1.25 pounds/1,000 gallons results. The final product will contain 400 to 500 ppm inorganics. Unit flows and consumptions for this flow sheet are shown in Table 12.

Table 12. UNIT CONSUMPTIONS BY ADSORPTION-ELECTRODIALYSIS

Volume product water	0.95 gal/gal feed
Volume to adsorber	1.0 gal/gal feed
Volume to electrodialyzer	1.0 gal/gal feed
Carbon makeup	0.075 lb/1,000 gal feed
H_2SO_4 required	1.2 lb 66° Be′ acid/1,000 gal

Fuel

No significant amount of fuel is consumed in the adsorption-electrodialysis process.

Electric Energy

Electric energy for electrodialysis is estimated at 6 kwh/1,000 gallons per stage including the pumping for that stage. In addition about 0.4 kwh/1,000 gallons will be required for pumping in the adsorption stage. This totals 6.4 kwh/1,000 gallons of feed, or for the nation, approximately 95 X 10^6 kwh/day. This is 3.5 percent of the current total U.S. electric energy generation.

Chemicals

The latest estimation [13] for H_2SO_4 requirements in adsorption-electrodialysis is 1.2 pounds of 66° Be' H_2SO_4/1,000 gallons of AWT feed. This is based on an average expected HCO_3 content of 310 ppm in the AWT feed. Applied to the model, the consumption would be 9,000 tons/day, or 2.6 percent of U.S. production.

The 0.075 pound per 1,000 gallons activated-carbon makeup amounts to 560 tons of carbon per day, which is 3.3 times the current production.

Electrodialysis Membranes

One component of electrodialysis equipment, the membranes, requires regular replacement and might be considered as "consumable." According to latest estimates [13] a 10-mgd plant required 38,600 square feet of membrane. Thus plants for 15,000 mgd would require 58 X 10^6 square feet of membrane, or at an average life of 5 years, 11.6 X 10^6 square feet per year replacement.

The electrodialysis industry is in its infancy, and so projections as to increases in present membrane production rates would be not possible. Furthermore, present production rates are unknown.

The total installed world capacity for electrodialysis, however, probably does not exceed 3 mgd so that application to the AWT model would involve a factor of the order of 5,000.

In summary, for AWT by adsorption-electrodialysis, as for the adsorption-distillation, the effect on the economy in fuel, electric energy, and H_2SO_4 would be inconsequential, but the activated-carbon production of the nation would have to be greatly expanded as, of course, would the electrodialysis membrane industry.

ULTIMATE DISPOSAL BY INCINERATION

The incineration process taken for study is that discussed in Reference 14. Case 2 from Table 2 of that reference is used as a basis of computation since it uses the largest size of furnace unit. When Reference 14 was written, it was not clear just what the concentration of AWT waste might be, and, accordingly, incineration was studied over the complete range of possible concentration. The development of the AWT research to the present, however, has suggested that AWT wastes probably will be quite highly concentrated; indeed, probably somewhere between 15 and 30 percent total solids, corresponding to 99.8 to 99.9 percent water recovery from an average secondary effluent. For that reason, in the present study the preconcentration steps were dispensed with, and the AWT waste was assumed to be the same as the 30 percent dry feed used in Reference 14.

The fuel consumption for the incinerator is 22×10^6 Btu/hour, or 1.41×10^6 Btu/ton of solids in the feed. Since the feed comprises 104,650 pounds/hour in the model 15 bgd of secondary effluent at 300 ppm contaminant content, 18,600 tons of contaminants per day is produced in the model. Thus, the fuel for incineration would be 26.4×10^9 Btu/day, or 0.02 percent of U.S. energy production.

At 792 kw[14] the electric energy consumption is 50.3 kwh/ton of solids in the feed. The national total would be 94×10^4 kWh/day, which is 0.03 percent of U.S. electric generation.

Applied strictly to the cases worked out in Reference 14, the 18,600 tons per day of contaminants would be reduced to 12,400 tons of inorganics after incineration. The average haul to the ocean, not considering the nonuniform geographical distribution of sewered conmunities, would be approximately that from Kansas to the Gulf of Mexico, or about 700 miles.. The railroad haulage then would amount to 0.7 X 10^6 ton-miles per day. In 1962 the railroads hauled 600,200 X 10^6 ton-miles of freight.[15] Thus, the railroad haulage of the incinerated solids would amount to about 0.5 percent of the national railroad ton-mile haulage. Motor trucks in 1962 hauled 331,900 X 10^6 ton-miles.[15] The AWT haulage would amount to about 0.9 percent of that total.

In summary, for ultimate disposal by incineration, the impact on the economy in fuel, electric energy, and haulage would be quite inconsequential.

ULTIMATE DISPOSAL BY PIPELINING

Trunk Lines

Work on another project in the AWTR Program[16] indicates that the scale economy in pipelining is great enough to demand that communities form into groups or cells for the purpose of combining their ultimate disposal of AWT wastes by pipelining. At 99.9 percent water recovery, the waste would amount to 15 mgd. It is too early to estimate how many combined trunk lines might be economic for the nation if this mode of conveyance were to be the only disposal method. If 100 trunk lines were the assumed requirement for transporting waste concentrates to the nearest ocean, the capability of the average pipeline would be about 0.15 mgd. At this flow rate, pipelining is more economic than rail tank-car or highway tank-truck at all distances.

The unit utilization of energy in pipelining is shown in Figure 7 For horizontal pipelining, the maximum energy requirement is in the neighborhood of 0.4 mgd capability and this maximum is at approximately 0.025 kwh/1,000 gallon-mile. As will be shown subsequently, the utilization of energy is so small that it does not matter what the capability of the pipeline is, and so how many trunklines one assumes does not matter.

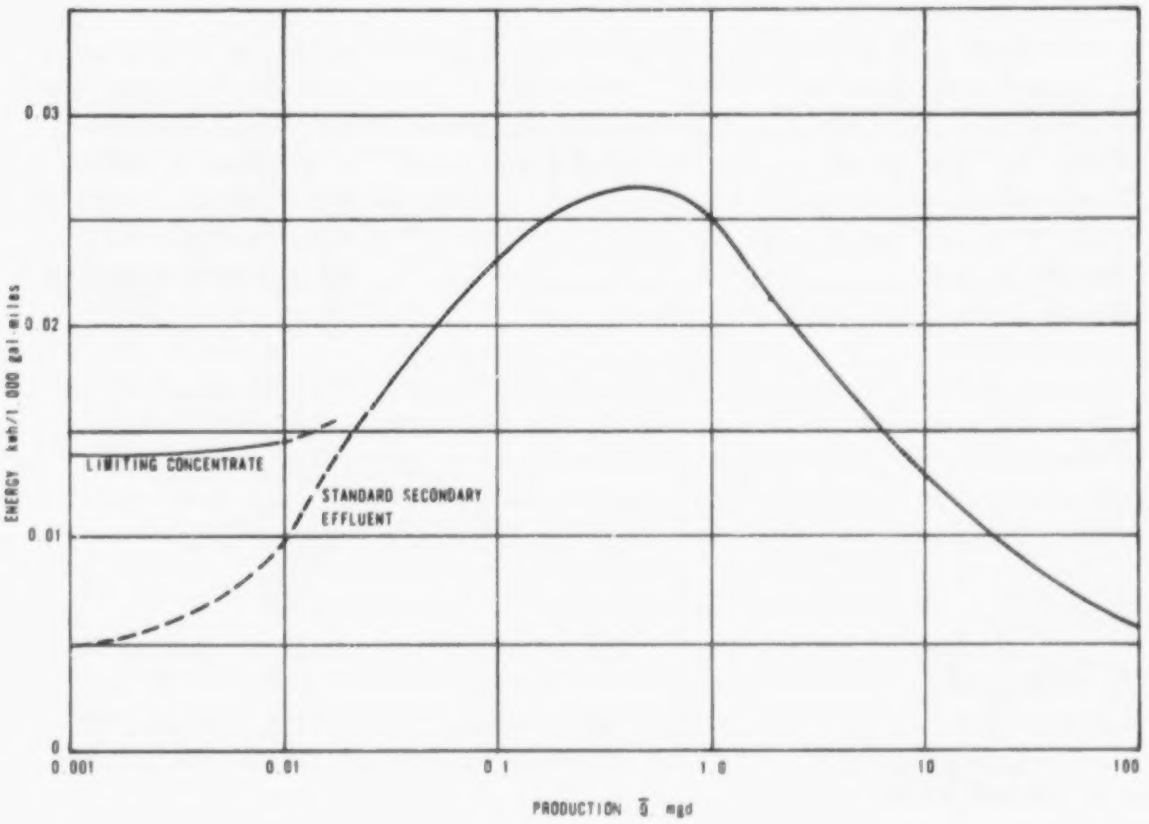

Figure 7. Unit utilization of energy in horizontal pipelining.

Assuming the transport of 15 mgd for a 700-mile average haul, the maximum electric energy consumption would be 2.6 X 10^5 kwh/day or about 0.01 percent of total U.S. electrical generation.

The ton-miles of pipelining for an average 700-mile haul would be 43.8 X 10^6 ton-miles per day. In the pipelining of crude oil and oil products (including gas) 660 X 10^6 ton-miles per day was handled in 1962[15]. Thus, the ton-miles of hauling for AWT waste would be about 6.6 percent of the current ton-miles utilized for pipelining of oil and oil products. This figure is also insensitive to the number of trunk lines assumed.

The pipeline mileage, however, is directly dependent upon the number of lines assumed. With the assumption of 100 lines, 70,000 miles of new line would be required. In 1962 crude oil and products pipelines amounted to 155,053 miles, and natural-gas pipelines and utility mains totaled 663,560 miles, for a total of 818,613 miles.[17] AWT pipeline mileage would amount to about 8.8 percent of the 1962 total.

About 410,000 of this total is distribution main for gas. If one excludes distribution mains from the computations, the AWT pipeline mileage would be about 17 percent of the present installed mileage. This figure is sensitive to the assumption as to the number of trunk lines. While such a figure (as 17 percent) presages a favorable economic climate for the pipelining industry, it by no means constitutes a logistical imbalance since installation of the 8 or 17 percent would be spread over a decade or more.

In summary, there do not seem to be any great impact or logistical imbalances in energy requirements for pipelining or in ton-miles conveyed. For total pipeline mileage there may be a slight impact, but this figure is highly dependent on the assumption, not now verifiable, of the number of trunk lines involved.

At 700 miles haul it is economic to preconcentrate to the equivalent of 99.9 percent recovery prior to pipelining at almost any flow rate and at any percent recovery below about 99.5. Thus at 98 percent recovery, for example, the utilizations computed for pipelining would be the same as for 99.9 percent.

ULTIMATE DISPOSAL BY HAULING

Very preliminary unverified projections as to optimum disposal grouping from the other current study under the AWT Activities[16] suggest that the pattern of group disposal by conveyance to the ocean will comprise a band around the coastline of the order of 100 miles. This conveyance will be by truck or rail, and not by pipeline.

In the remainder of the country, optimum group disposal from economic optimum cells would be by some of the other methods, i.e., injection, incineration, etc.; however, the sizes of the cells and the daily volumes involved for the various segments of the hauls are such that this collection, estimated as of the order of 2 X 10^6 ton-miles/day, would also be by truck or rail and not by pipeline.

Accordingly, if hauling turns out to be the real pattern of ultimate disposal, there will be no ultimate disposal by pipelining and, thus, no possibility of logistical imbalance in that sphere.

ULTIMATE DISPOSAL BY INJECTION

Injection wells for ultimate disposal also show a strong scale economy, but this vanishes at 2 mgd, which is about the highest capability that can be taken for an injection well. As with pipelining, it is uncertain what the optimum grouping might be; but, for the present study, let it be assumed, as the worst case, that every sewered community on AWT in the model has, on the average, one injection well. This would mean a total installation of 11,000 wells.

The total number of producing oil and gas wells in operation at the end of 1962 was 596,385.[17] The 11,000 wells would amount to 1.8 percent of the existing wells.

In 1962 the oil and gas industry completed 44,000 wells (not including exploratory and test holes). The capability of the industry is higher than this, however. In 1957, for example, 57,000 wells were completed. Accordingly, the drilling industry could complete the 1962 compliment of 44,000 wells plus 11,000 wells for ultimate disposal in a single year, and still have several thousand wells capacity to spare.

The total footage drilled in 1962 was 198.5×10^6 feet. The average depth of wells drilled in that year was 4,300 feet. This depth is probably about the minimum that would be necessary for injection wells for ultimate disposal of AWT wastes. If the average ultimate disposal well reached 10,000 feet, 110×10^6 feet of drilling would be needed. This is about 55 percent of 1 year's footage in the oil and gas industry. Again, this would be a favorable climate for the drilling industry, but it would by no means upset the economy. In the first place, probably not more than one-half of the nation is suitable for injection wells, and in the second place the construction of such injection wells for AWT would be spread over a decade or more.

Chapter 6. PROCESSING PROCEDURES

INTRODUCTION

This chapter details the processing procedures and computations that were used in producing the data on which chapters 3 or 4 are based.

The basic sources of data are the Inventory of Municipal Waste Facilities (IMWF), 1962,[18] and the Municipal Water Facilities Inventory, Communities of 25, 000 Population and Over, 1962.[19] The statistical summary of the 1962 IMWF has not yet been issued, but that for the 1957 Inventory 1 showed a total of 11,131 sewered communities. The 1962 Inventory probably contains more than this number. On the other hand, not every entry in the Inventory resulted in an entry in the present study since some of the entries for multiple facilities with discharges located close together were combined for the present study.

Since some of the entries lacked data for the volume of sewage flows, these missing entries were synthesized by application of an average per-capita-sewage-flow figure for each state. These average per capita sewage flows, $\overline{PC}$'s, were developed from those entries in each state for which both population or population served and volume of sewage flow were given.

The processing of the data consisted of the determination, operating by a set of rules on the information given for each entry of Q, the volume of sewage flow; Q, the volume of sewage reaching the stream; g, the fraction of the sewage flow that reaches the stream; f, the fraction of BOD removed before discharge; and Qf, the fraction of BOD removed, weighted by the flow reaching the stream.

In the West, where discharge to irrigation uses is common, these computations were made separately for the irrigation discharges, for the nonirrigation discharges, and for their sums.

The data for each community were plotted on 1:1,000,000-scale drainage basin maps and cumulated downstream for the main streams and major tributaries, accumulation points being at their confluences. The accumulation points represented at least 95 miles of stream, and there was an accumulation point for every stream or reach of 95-mile length. The cumulations gave total waste flow reaching the stream and fraction BOD removed, weighted by total waste flow reaching the stream, both for the non irrigation flow and for the total flow.

For determining the fraction of upstream wastes in surface water sources, 155 cities having single surface water sources and a population greater than 25,000 were selected.

DETERMINATION OF AVERAGE PER CAPITA WASTE FLOW

Not all of the entries in the IMWF provide data on the volume of sewage flow; however, some of the entries lacking flow figures did provide population or population-served data. To generate flows from population or population-served data, it was necessary to develop average per capita waste flows. This was done for each state and for three population classes in each:

Less than 10,000 population or population served, $\overline{PC}_1$
10,000 to 100,000 population or population served, $\overline{PC}_2$
Greater than 100,000 population, $\overline{PC}_3$.

For each state and population category, the total population or, preferably, population served, and the total flow for all entries were summed to provide both sets of data, with the following exceptions. For a number of entries the listed flow corresponded precisely to 100 gallons per capita per day (gpcd). It was considered that these had been estimated by application of a highly conventionalized gpcd factor, and these were excluded from the $\overline{PC}$ computation. Other estimated flows not resulting from a precise 100-gpcd factor were included in the computation with the thought that the estimate was an actual estimate and represented the approximate flow. The results are shown in Table 13.

The resulting average per capita flows, $\overline{PC}$'s, are as follows:

$\overline{PC}_1$ = 131 gpcd
$\overline{PC}_2$ = 120 gpcd
$\overline{PC}_3$ = 155 gpcd
$\overline{PC}_{all}$ = 141 gpcd

Table 13. PER CAPITA WASTE FLOW, BY STATES AND POPULATION CATEGORIES

State	$\overline{PC}_1$, gpcd	No. of entries used	$\overline{PC}_2$, gpcd	No. of entries used	$\overline{PC}_3$, gpcd	No. of entries used	$\overline{PC}_{all}$, gpcd
Alabama	137	32	124	9	-	-	127
Arizona	77	66	128	10	86	1	101
Arkansas	94	24	59	11	-	-	68
California	330	270	55	93	103	16	104
Colorado	355	13	96	1	160	1	147
Connecticut	138	53	137	28	187	3	151
Delaware	140	7	-	-	253	1	242
Florida	119	134	143	21	135	2	134
Georgia	119	128	125	15	84	4	100
Idaho	295	32	164	7	-	-	199
Illinois	99	363	117	53	259	5	211
Indiana	134	52	174	37	177	6	171
Iowa	115	147	172	11	79	1	136
Kansas	96	182	93	21	67	1	91
Kentucky	157	5	132	2	-	-	136
Louisiana	115	51	146	8	-	-	135
Maine	173	5	181	1	-	-	177
Maryland	245	1	-	-	-	-	245
Massachusetts	178	71	125	23	154	3	147
Michigan	112	141	136	36	88	5	114
Minnesota	96	21	105	3	139	1	135
Mississippi	149	2	194	2	-	-	164
Missouri	73	77	199	7	-	-	149
Montana	198	74	168	5	-	-	181
Nebraska	150	26	-	-	-	-	150
Nevada	138	18	151	4	-	-	149
New Hampshire	178	9	230	1	-	-	197
New Jersey	152	11	152	8	386	2	346
New Mexico	85	51	101	4	110	1	101
New York	132	211	141	48	143	14	142
North Carolina	131	179	120	22	136	1	125
North Dakota	112	29	58	4	-	-	71
Ohio	112	204	119	65	156	11	135
Oklahoma	92	210	98	18	107	2	99
Oregon	199	21	162	7	-	-	173
Pennsylvania	100	287	103	46	125	5	112
Rhode Island	134	17	134	6	173	2	156
South Carolina	96	110	151	12	-	-	150
South Dakota	84	174	123	9	-	-	105
Tennessee	146	40	158	11	228	2	185
Texas	95	374	95	60	107	8	100
Utah	165	18	174	8	174	1	173
Vermont	204	18	158	3	-	-	184
Virginia	203	55	192	1	75	1	124
Washington	179	57	190	16	-	-	187
West Virginia	89	1	64	1	-	-	47
Wisconsin	126	350	178	29	188	2	171
Wyoming	178	3	109	2	-	-	110

The national average flow is 141 gpcd; however, the per capita flow to be used to generate the highest percentage of correct community flows is 131 gpcd since communities in the less-than-10,000-population category are, by far, the most numerous in the IMWF.

Figure 8 shows, for this most numerous category, the $\overline{PC}_1$ for the various states in an attempt to determine whether any regionalization of $\overline{PC}$'s is possible. The region of highest $\overline{PC}$'s is in the Northwest on the arc from Colorado to California, where the range is 178 to 330 gpcd

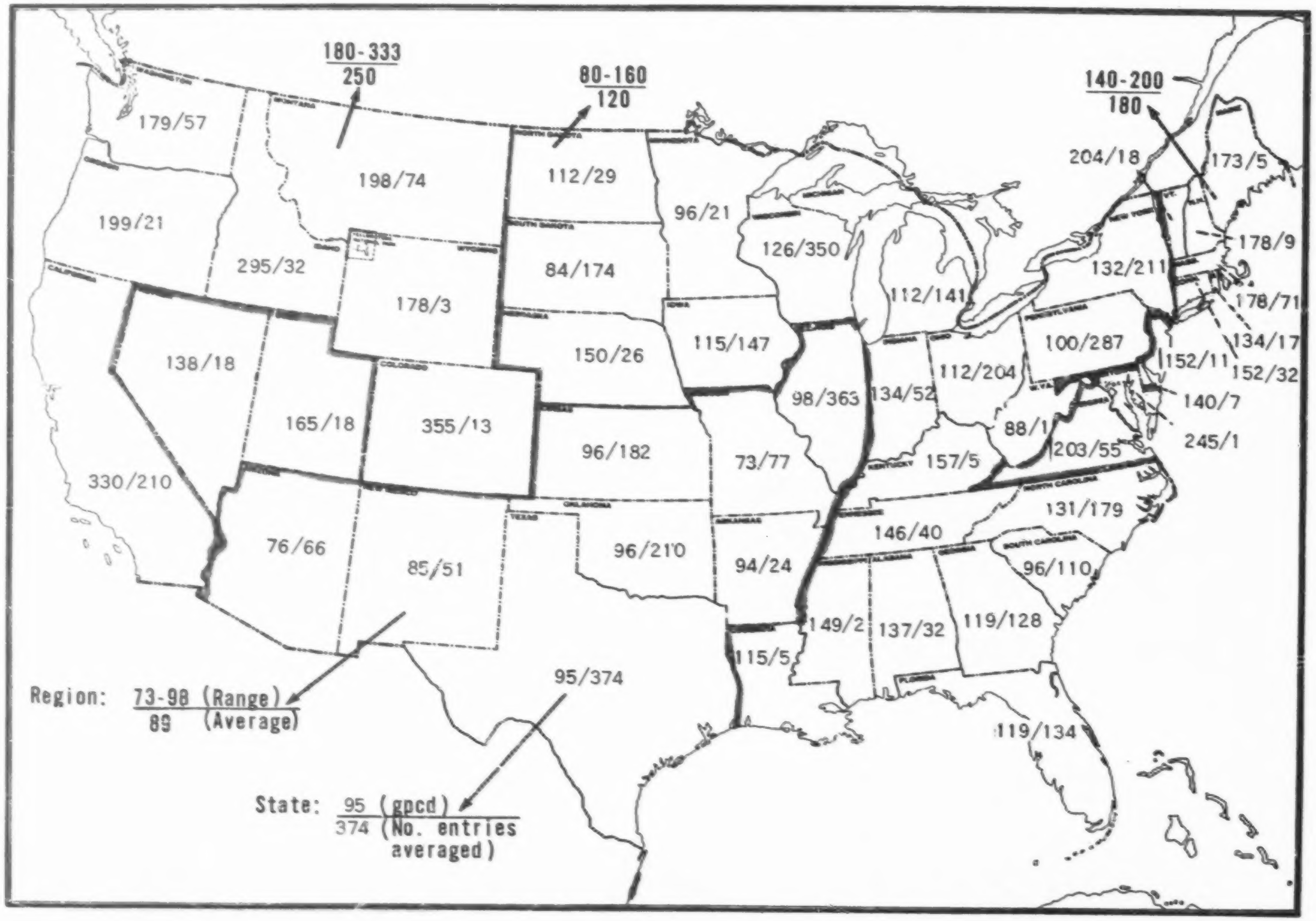

Figure 8. Average waste flows by state and region for communities with a population of less than 10,000.

and the average 250. The region of lowest $\overline{PC}_1$'s in the nation is the contiguous southwestern arc from Arizona to Illinois with no state $\overline{PC}_1$ above 100. Nevada and Utah are intermediate between the above two regions. Another high $\overline{PC}_1$ region is the northeastern arc from Virginia to Maine, where the average is 180 gpcd. The remainder of the country from Florida to Michigan and Michigan to the Dakotas is in the middle range and somewhat heterogeneous. The map presents the distribution of $\overline{PC}_1$'s. Note that the average $\overline{PC}$ for all available cities in each state may be quite different from the $\overline{PC}_1$, as may be seen from Table 13.

Inspection of Table 13 suggests that the trend of $\overline{PC}$'s with population is quite erratic; however, application of the statistical sign test to the 48-state data shows that there is an upward trend from $\overline{PC}_1$ to $\overline{PC}_2$ at a 0.25 level of significance. This means that the probability is only 0.25 that the upward trend conclusion is incorrect. The test applied to $\overline{PC}_2$ and $\overline{PC}_3$ indicates an upward trend at the 0.25 level of significance, meaning that the probability that there is no such trend is only 0.05.

The $\overline{PC}$'s so developed were applied to the appropriate entries lacking flow data in the processing step to generate synthetic waste volumes as described in the next section.

PROCESSING IMWF DATA

Introduction

The following symbols and concepts were used in the processing:

Q_o = Discharged from plant, mgd
g = Fraction of Q_o that reaches the stream
Q = Flow resulting from Q_o that reaches the stream, mgd
f_e = Estimated fraction of BOD removed from Q before discharged to stream
f_p = Known fraction of BOD removed from Q before discharge to stream
f = Final choice for fraction of BOD removed from Q before discharge to stream
Q_f = Fraction of BOD removed, weighted by flow reaching stream.

The aim of the processing is to develop a set of two numbers associated with each sewered community, one representing the volume contribution of waste liquid reaching the stream and the other representing the fraction of BOD removed in treatment, weighted by the flow reaching the stream. In the cumulation and summation for the final use to which these data are put, $\Sigma (Qf)/\Sigma Q$ becomes the weighted fraction of BOD removed, and hence, the f index number measuring the weighted degree of treatment of upstream discharges.

Determination of g

The first step in the processing is the determination of g, the fraction of the discharge that reaches the stream. Before proceeding to that determination those entries for which there was no population, population served, volume discharged, or design volume were eliminated. For these entries there was no possibility of computing a discharge rate. It was also possible to eliminate from further processing those entries in which the population served was included in some other facility already existing as an entry.

For the remaining entries, the determination of g fell into six cases, as follows.

In case I, g was taken as zero; and, since this meant that none of the discharge reached a stream of interest to the study, the entry could be excluded from further processing and plotting. This case comprises those entries in which the "discharge to" column contains:

Industrial reclamation
Ocean
Slough (on coast or tidewater)
Bayou (on coast or tidewater)
Tidewater
Bay
Gulf
Drainage well (greater than 1,000 feet deep and
near the seacoast).

In case II, g was taken at 1.0; in other words all of the Q reached the stream without evaporation or transpiration. This case was composed of entries in which the "discharged to" column included:

Wet weather lake
Lake (no effluent)
Lagoon
River, creek, or tributary
Lake
Drainage ditch
Slough (if inland)
Bayou (if inland)
Dry run to some river
Ditch to some river

Any other category "to some river"
Lava sink hole
Subsurface
Canal
Swamp
Channel
County ditch
Seepage lagoon
Drainage well (less than 1,000 feet deep)
No discharge (when treatment column indicated lagoon)

For case III, g is taken as 0.20 since the discharge is assumed to be similar to irrigation in which water spreads intermittently and a considerable amount of evaporation and transpiration occurs before the effluent reaches the ground water body. Once it reaches the ground water body, it ultimately finds its way into the stream. The point of entry into the stream may be far removed from the discharge point; but because there is no way to determine this point, it is taken as occurring near the discharge point. The reasoning also applies to the nonidentity of the surface water divide with the ground water divide. Entries were taken as case III if they appeared unqualified. If they appeared with a qualification that indicated they were a direct channel to some river, for example "dry creek to (named) river," they were placed in case II. Case III occurred when the "Discharge to" column contained:

Dry gulch
Dry water course
Dry creek
Dry draw
Dry channel
Dry tributary
Dry ditch
Ditch
Dry bed
Ravine
Draw
Roadside ditch
Gully
Storm ditch
Wash
Arroyo
Watershed, when irrigation appeared in treatment column.

Irrigation, no effluent (if due to irrigation)
Land
Percolation, no discharge

Entries containing no information in the "discharge to" column and having no other apparent way of being determined were placed in case IV. The g for this case was arbitrarily taken at 1.0 unless irrigation was indicated in the treatment column; in this case, g was taken at 0.20.

Entries in which the treatment column contained an evaporation lagoon were placed in case IV. The g was arbitrarily taken as one-half of the g determined from case II or III. This is based on the assumption that, in an evaporation lagoon, on the average about 50 percent is evaporated and the remainder is lost by seepage or overflow.

Entries indicating a seasonal population load were placed in case VI. The g was taken as one-third the values determined by the preceding formula.

Determination of f

This fraction is the fraction of BOD removed from Q before it reaches the stream. It is not precisely the residual BOD reaching the stream divided by the original BOD. The reason is that, if evaporation occurs on the way to the stream, this evaporation will remove water but not BOD. In certain cases, f, the final choice, may be directly determined from the "discharge to" column if "percolation" is indicated. Here, an f of 0.90 is assigned[20]. Entries indicating "percolation" were placed in case I and were those whose "discharged to" column was designated:

Wet weather lake
Lagoon
Lake (no effluent)
No effluent
Land
Percolation
Draw
Seepage lagoon
Drainage well
No overflow
Lava sinkhole
Subsurface
No discharge

The following apply if the entry is not qualified by "to some river." If that is the case, f cannot be taken as 0.90, but must be determined as in the following section.

Storm ditch
Irrigation
Dry creek
Dry channel
Dry ditch
Roadside ditch
Wash
Dry water course
Dry draw
Dry tributary
Ditch
Gully
Arroyo
Watershed if irrigation occurs in treatment column.

All other entries not in case I are placed in case II. For these entries the procedure is to determine f_e and f_p, the estimated and precise fractions removed, and on the basis of these to decide which will be chosen as the final f.

The estimated fraction removed, f_e, is determined by the listing in the treatment column as follows:

Aeration, trickling filter, oxidation lagoon, or irrigation: $f_e = 0.90$
Intermittent filter: $f_e = 0.70$
Settling tank or settling lagoon: $f_e = 0.35$
None of the above: $f_e = 0$.

The f_e assigned corresponds to the treatment type that produces the highest f_e from the above list. The figures 0.9, 0.35, and zero are assigned as conventional fractions removed for secondary treatment, primary treatment, and no treatment as agreed upon in discussions with USPHS personnel[21].

The figures of 0.70 and 0.50 for intermittent sand filters and rapid sand filters were assigned as the result of a sample study of entries with a known f_p that had rapid or intermittent sand filters other than those included in a system also involving secondary treatment or lagoons. The average for six rapid sand filter entries was 0.51, and for 21 intermittent sand filter entries was 0.77.

The IMWF gives, in many cases, the population equivalent (PE) of the discharged wastes and the population equivalent of the untreated wastes. If these data are given, the precise fraction removed is computed by:

$$f_p = 1 - (\text{PE treated waste}/\text{PE untreated waste})$$

If no data are given in the population equivalent column, then f_p cannot be computed.

For entries falling in case I determined by the "discharge to" column, the final selection, f, is 0.90 regardless of f or f_p. If there are no data in the population equivalent column, f_p cannot be computed; and, if the entry is not a case I entry with $f = 0.9$, the f is taken as f_e.

If both f_e and f_p are available, then the choice of the final f is made according to the following:

If $f_e = 0.9$ and $f_p = 0.46$ to 1, choose $f = f_p$; but
if $f_e = 0.9$ and $f_p = 0$ to 0.45, choose $f = 0.9$

If $f_e = 0.35$ and $f_p = 0$ to 0.49, choose $f = f_p$; but
if $f_e = 0.35$ and $f_p = 0.50$ to 1, choose $f = 0.35$

If $f_e = 0$ and $f_p = 0.24$, choose $f = f_p$; but
if $f_e = 0$ and $f_p = 0.25$ to 1, choose $f = 0$.

The basis of this selection is the usual discrepancy between the estimated or conventional fraction removed, f_e, and the computed or precise fraction removed, f_p. When f_p differs slightly from f_e, the discrepancy is assumed to be due to normal variation in operating efficiency. When the f_p differs widely from f_e, the final chosen f is taken as f_e. An analysis of some of these data is given in another section.

A similar rule was not established for f_e's of 0.50 or 0.70 resulting from intermittent sand filters or rapid sand filters. Accordingly, if f_e was assigned 0.50 or 0.70 by virtue of this type of treatment, the final f was taken as f_p if availableand f_e if not.

Determination of Q_o

Q_o is the sewage flow of a community. If the flow is given in the IMWF and is not the product of population served times 100 gpcd, then the figure given in the IMWF was taken for Q_o.

If the flow was not given or was the result of multiplying a population served by 100 gpcd, Q_o was obtained by the application of the appropriate $\overline{PC}$ (for the population class and state) to the population served if given, or if not given, to the 1960 population. If Q_o could not be determined in this manner for lack of information, then it was assumed that the average flow was 50 percent of the design flow and Q_o was taken as 0.5 times the design flow as given in the IMWF. If the design flow in turn was not given, the entry was eliminated from further processing and plotting.

Computation of Q and Qf

Having determined g, f, and Q_o, there remains the computation for each community of:

$$Q = gQ_o \text{ and } Q = gfQ_o.$$

Q is the volume of effluent from a community that actually reaches the stream and Qf is the figure indicating the degree of treatment weighted by the volume of effluent that reaches the stream.

Treatment of Irrigation Discharges

Irrigation as a final disposition of a sewage discharge was given an f_e of 0.9, which reflects the high degree of treatment achieved by intermittent spreading. Irrigation discharge is uncommon in the East, but quite common in the West. The possibility thus arose that a stream would show an f index of 0.9 largely because most of the discharges in its basin were for irrigation. By the system used, such a stream would be considered in the market for AWT; however, this would not actually be the case.

When secondary treatment yields an f of 0.9, the discharge is concentrated in one process stream, i.e., the secondary treatment plant effluent being discharged. Such a stream could be conveyed to an advanced waste treatment plant and utilized as feed. When the 0.9 is achieved as a result of irrigation; however, this 0.9 liquid is not recoverable for use as AWT feed. Accordingly, it would be an error to place in the AWT market the river basins in which the 0.9 discharge was obtained largely through irrigation use.

The ambiguity in the results brought about by this concept cannot be completely eliminated because the same cumulation of Q, the volume discharge reaching the stream, was to be used, for determining both the cumulative f index and the percentage of upstream wastes in surface supplies. In an attempt to quantify the ambiguity and to allow a rejection of a 0.9 stream if warranted by a high fraction of irrigation discharges, a separate cumulation was made of the Q and Qf of irrigation discharges, land applications, etc. The cumulations actually made, therefore, were Q and Qf for nonirrigation discharges and Q and Qf for irrigation-type discharges.

Tabulations of the type shown in Table 1, chapter 3, were made of accumulation points having f index factors from nonirrigation discharges greater than 0.8. Then, for these points, the corresponding f index for all discharges was tabulated, and a number of accumulation points for which the f index for nonirrigation discharges was less than 0.8 but the f index for all discharges was greater than 0.8 were added to the table. The number of entries so added to the table was 16, excluding those made up almost exclusively of irrigation discharges and thus excluded from the AWT market. All of these 16 were in Texas. One of them fell in the f = 0.85 to 0.90 class, and the remaining 15 fell in the f = 0.80 to 0.85 class. Analysis then showed that of all of the entries in the table, only a very few had an appreciable portion of irrigation-type discharges, and these are the ones indicated in footnotes b and c of Table 1.

A further study showed that a very high percentage of the discharges used for irrigation were already in the 0.90 class prior to the irrigation use. Thus, a process stream of f = 0.9 was, indeed, actually available and could have been used as a AWT feed. Further consideration, however, develops the concept that, if such discharges were diverted to AWT and away from irrigation, an equal amount of water would have to be supplied from some other source for irrigation, so that the irrigation economy would not be upset. Thus, the concept that such basins are excluded from the AWT market applies regardless of whether the processed stream is at 0.9 before the irrigation application.

PLOTTING AND CUMULATION OF DATA

The basic maps on which the data were plotted and cumulated were the River Basin maps provided by the Interagency Committee on Water Resources [22]. These maps, in 80 sheets, cover the drainage basins of the nation and show all surface streams (and hydrologic stations) on the scale of 1:1,000,000. Also used in plotting, where the communities were very dense, were the corresponding maps from a 1959 edition of that reference of the scale of 1:625,000. Plotted on these maps were the communities corresponding to the IMWF entries, approximately 11,000 of them, the Q value, the f value, the Q and f values for that portion of the discharge that was of the irrigation type, and a dot locating the stream that the discharge reached.

The maps were then divided into drainage basins for cumulation. Drainage basins for cumulation were drawn so as to comprise at least 6 inches (about 95 miles) of stream including first- or higher-order tributaries. If a tributary and one or more of its successive tributaries was 6 inches long, a drainage area was drawn around its drainage basin and an accumulation point placed at its confluence with the main stream. If a tributary was less than 6 inches in length, it was not cumulated separately, but was included in the main stream at the point of confluence without an accumulation point. If this procedure left a length of stream greater than 12 inches without a cumulation point, then an arbitrary accumulation point was set 6 inches upstream from the last accumulation point reading upstream. The result was that all streams separately cumulated were between 6 and 12 inches in length. Streams less than 6 inches in length were not separately cumulated; and, if they were coastal streams, i.e., not tributary to a main stream, then they were not cumulated at all.

At a confluence, accumulation points were placed on the tributary and on the main stream above and below the confluence. Accumulation points were also placed at the points where a stream left a map.

For international boundary streams and for streams that entered the United States from Canada or had portions of their course in Canada, it was not possible to obtain the data for the municipal discharges in Mexico or Canada. Accordingly, the cumulations involve only the United States contributions to such rivers.

SELECTION OF CITIES FOR CUMULATION

To determine fraction of streamflow comprised of upstream municipal wastes, it was necessary to select a number of cities for study. Cities selected had to have a surface supply; only one source, one river or one reservoir; and a river that had a nearby gaging station. Such cities were selected from the Municipal Water Facilities Inventory.[19] There are 414 cities of over 25,000 population supplied by surface water; of these, only 155 fit the above criteria. One reason for this was that many of the 414 entries constitute suburban districts to major cities and to separate out the close-lying intakes would not have been profitable.

A nearby gaging station was selected, and the flow at the gaging station was considered to be the flow at the municipal intake with the exception that an adjustment was made for confluences and discharges occurring between the gaging station and the approximate location of the municipal intake.

The river-flow data used were from Water Year 1961 (October 1960-September 1961) as appearing in reference 23. The two flows chosen were the average streamflow for 1961 and the average flow for the minimum flow month for 1961. The year was approximately contemporary with the data in the Inventory Municipal Waste Facilities. The minimum flow was chosen somewhat arbitrarily and largely because the only other available minimum, that for the minimum day, seemed too extreme for general use.

In a few cases some radical error may have been introduced because of lack of precise knowledge concerning location of a municipal intake. For example, if a selected gaging station is below a reservoir, but the actual municipal intake is from the reservoir, then the average and minimum flows at the gaging station may not represent the average and minimum flows entering the reservoir. For the most part, the probability is high that the average flow below the reservoir when adjusted for the withdrawal from the reservoir will approximate the average flow into the reservoir, i.e., the change in reservoir contents over a 1-year period will be small compared to the total annual flow. This is not the case for minimum monthly flows, however. The minimum monthly flow below a reservoir may be zero while the minimum monthly flow above the reservoir is some positive value. In such cases, the tabulated figure for the percentage of upstream waste in the minimum monthly flow at the intake would be in major error.

Even in the case in which the gaging station is upstream of the reservoir but the intake is from the reservoir, there will be a major error in the low flow percentage because of the fact that the composition of the reservoir with respect to upstream municipal wastes will represent some average because of mixing, unless it happens that during the low flow month the reservoir contents were at a very low stage. A considerable amount of detailed work on individual cases would have been required to eliminate errors of this type, starting with the primary difficulty that, in many cases, the IMWF cites as a source only the river involved without describing whether the withdrawal is by way of a reservoir. Since the purpose of the study was to obtain some general nationwide indications, such an amount of work to obtain accuracy in such exceptional cases was not warranted.

In a few cases, the data presented may not be truly representative of the conditions at the municipal intake because of some deviation from a typical surface-water supply situation, usually involving multiple sources, which were taken here as a single source. For example, for the city of Shreveport, entry No. 33 in Table 7, the municipal source is Cross Lake of which a principal tributary is Paw Paw Bayou. Paw Paw Bayou has the only gaging station in the vicinity and, therefore, was chosen as the gaging station for Shreveport. The only municipal discharge reaching Cross Lake is from Waskom, Texas, a small community having land discharge. (Indeed it is not certain whether this Waskom discharge reaches Paw Paw Bayou or reaches Cross Bayou, another tributary to Cross Lake. The data in the table are computed as if the Waskom discharge occurred to Paw Paw Bayou.) The percentage given, then, is not the percentage for the Shreveport intake at the head of Cross Lake, but the percentage at the point must be less than the percentage given in the table, since Waskom's discharge certainly reaches Cross Lake and the flow into Cross Lake is greater than the flow from Paw Paw Bayou. There may be other errors of this general type relating to multiple sources in the table, but it would not be possible to eliminate all of them short of a field study for the conditions in each city.

In addition to the cumulations made to confluences, cumulations of Q were also made to the selected gaging stations from which the percentage of upstream municipal waste in the flow was computed.

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APPENDIX
ADVANCED WASTE TREATMENT RESEARCH PUBLICATIONS

Although over-all guidance of AWTR projects is provided by the AWTR Program, the results obtained, opinions expressed, and conclusions reached by the contractors are theirs and are not necessarily endorsed by the U. S. Department of the Interior. Except for editorial review and abridgments as necessary, these reports appear as received from the contractors.

		Report Number
AWTR-1	Summary Report, June 1960 - December 1961	W62-9
AWTR-2	Preliminary Appraisal of Advanced Waste Treatment Processes	W62-24
AWTR-3	Ultimate Disposal of Advanced Treatment Waste Part 1. Wet Oxidation Part 2. Incineration	999-WP-3
AWTR-4	Waste-Water Renovation Part 1. A Design Study of Freezing and Gas Hydrate Formation Part 2. Feasibility Tests of Freezing	999-WP-4
AWTR-5	Contaminant Removal from Sewage Plant Effluents by Foaming	999-WP-5
AWTR-6	Cost of Purifying Municipal Waste Waters by Distillation	999-WP-6
AWTR-7	Advanced Waste Treatment by Distillation	999-WP-6
AWTR-8	Ultimate Disposal of Advanced-Treatment Waste	999-WP-10

Part 1. Injection
Part 2. Placement in Underground Cavities
Part 3. Spreading

AWTR-9	Adsorption of Biochemically Resistant Materials from Solution. 1.	999-WP-11
AWTR-10	Feasibility of Granular, Activated-Carbon Adsorption for Waste-Water Renovation. 1.	999-WP-12
AWTR-11	Evaluation of the Use of Activated Carbon and Chemical Regenerants in Treatment of Waste Water	999-WP-13
AWTR-12	Evaluation of Various Adsorbents and Coagulants for Waste-Water Renovation	999-WP-14
AWTR-13	Electrochemical Treatment of Municipal Waste Water	999-WP-19
AWTR-14	Summary Report: The Advanced Waste Treatment Research Program. January 1962 through June 1964	999-WP-24
AWTR-15	Feasibility of Granular, Activated-Carbon Adsorption for Waste-Water Renovation. 2.	999-WP-28
AWTR-16	Adsorption of Biochemically Resistant Materials from Solution. 2.	999-WP-33
AWTR-17	Studies Relating to Market Projections for Advanced Waste Treatment	WP-20-AWTR-17

GPO 829-647-